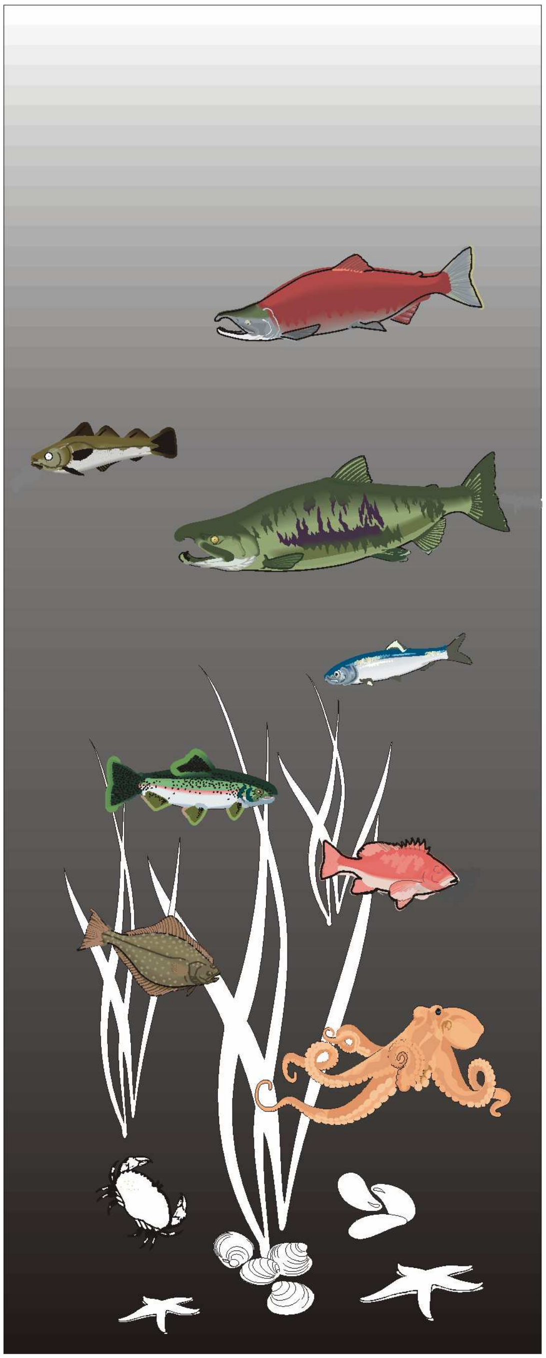
Northwest Fishery Resource Bulletin



Puget Sound Chinook Salmon (*Oncorhynchus tshawytscha*) Escapement Estimates and Methods - 1991

By

Carol J. Smith and Pete Castle

Washington Department of Fish and Wildlife

Project Report Series No. 1

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Project Report Series

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September 1994

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ABSTRACT

Escapement estimates are used to predict future run sizes, regulate fisheries, and monitor trends in run sizes, run timing, and the distribution of chinook salmon in Puget Sound. This report documents the methods used to estimate the escapement of chinook salmon to various systems throughout Puget Sound and suggests areas for future improvement. Ground, raft, or aerial surveys are conducted weekly during the spawning season by trained personnel to enumerate live adults, dead adults, new redds, and visible redds for each surveyed river system. Cumulative redds, peak live adults, cumulative carcass counts, or area-under-the-curve integration of either visible redds or live adults are the methods most often used to estimate escapements. The estimation method is different for different river systems and depends upon the cost of the different survey types, river visibility and flow conditions, and the desire to maintain consistency with past estimates, balanced with increasing the accuracy of the estimate. Data and estimation methods used to estimate the chinook salmon escapements in 1991 are described to provide specific examples of how the various methods are used by fisheries biologists from the Washington Department of Fish and Wildlife (WDFW) and Puget Sound Tribes to estimate escapements.

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INTRODUCTION

Background

Escapement estimates are an important component in estimating run sizes, forecasting future run sizes, assessing the success of fishing regulations, establishing escapement goals, and analyzing trends in relative abundance, run timing, and geographical distribution. A variety of methods are used to estimate the escapement of chinook salmon (*Oncorhynchus tshawytscha*) to river systems in Puget Sound. The choice of a method depends upon the degree of accuracy required, cost, water visibility and accessibility, and a desire to maintain consistency over time. Many of the escapement estimation methods for chinook salmon in Puget Sound have changed considerably since Ames and Phinney (1977) last described the escapement estimation methods for chinook salmon in Puget Sound.

Objectives

The majority of the escapement estimates of naturally-spawning chinook salmon are actually relative (year to year) estimates of abundance rather than estimates of total escapement. The purpose of this report is to document the current methods used by the Washington Department of Fish and Wildlife (WDFW) to estimate the escapements of chinook salmon in Puget Sound. In addition, areas for future study are suggested. For this report, escapement data for 1991 are used as examples to illustrate how the different estimation methods are applied to each drainage.

Geographical Area

This report is organized by river basin, with the major river systems in Puget Sound shown in Figure 1.

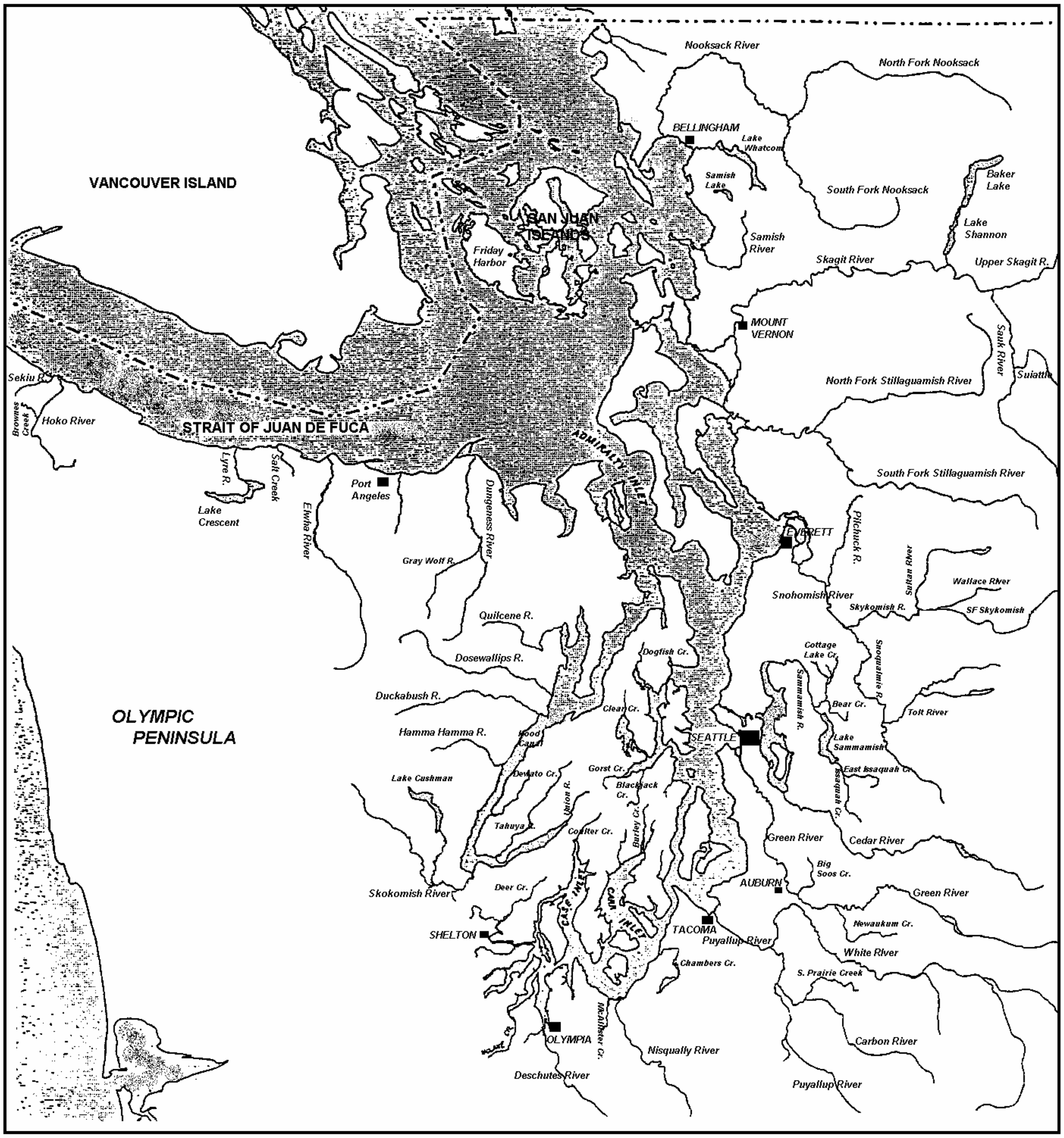

Figure 1. Major Washington State drainages that empty into Puget Sound. Many support significant populations of naturally-spawning chinook salmon.

METHODS

Surveys

Surveys are conducted at weekly intervals when weather conditions and river levels allow and are scheduled to span the duration of each run based upon previous years' data. Observers wear Polaroid glasses during surveys to reduce glare. Percentage visibility is estimated by surveyors for each river section. Counts are made of live adult chinook salmon, dead chinook salmon, and visible chinook salmon redds.

Dead chinook salmon are marked by caudal fin cuts to prevent double-counting on future visits in those systems which depend upon carcass counts as a measure of abundance or in systems where scales are sampled. Dead fish are also checked for adipose fin clips. When a fin clip is found, the snout of the fish is removed, labeled, and sent to the WDFW coded-wire tag laboratory. Visible redds are defined as any redd that can be identified as a chinook salmon redd during the survey, including both new redds and previously counted redds. For index sections and some entire rivers, the date and location of newly constructed redds are recorded. These redds are marked by securing flagging to a nearby permanent object. For these surveys, new redds as well as visible redds are counted at each visit and recorded as new and/or visible redds. Cumulative redds are calculated by summing the number of new redds identified during the season. In addition, the presence of other species of salmon is noted.

Survey areas span most of the range of chinook salmon spawning habitat. Index sections are chosen as representative sections of major river systems where cumulative new redd counts as well as live and dead adult counts are recorded. Supplemental sections are surveyed on a weekly basis on the same day as the index sections, but only visible redds and live and dead fish are counted; cumulative new redds are not recorded in the supplemental areas.

Surveys are conducted by foot, raft, or aircraft, depending on the size and accessibility of the river system. Data are recorded in field books and subsequently transferred to cards for entry into a database.

Data Analysis

The estimation method used depends upon the type of data available. When cumulative redd counts are available, total redds are calculated as the number of new redds constructed in the survey area during the survey period. The total number of redds is then multiplied by 2.5 adults/redd to estimate the total escapement to an area. The value of 2.5 adults/redd is derived from the sex ratio of 1.5 males for each female observed for chinook salmon in the Skagit River system (Orrell 1976).

For a few river systems, such as the Dungeness, cumulative redd counts are available for the entire range of chinook salmon spawning habitat and no additional expansion is necessary. For many other systems, a defined index area is surveyed each year using cumulative redd counts. New redds, visible redds, live adults, and dead adults are counted. Cumulative redds and the estimated number of adults are calculated as described above to provide an escapement estimate for the index area. Supplemental sections of the river are surveyed weekly for visible redds to expand the index escapement number to the remainder of the system. New redds are not marked during supplemental surveys but live and dead adults are counted. Escapement in the supplemental areas is calculated using the escapement value from an index area and peak visible redd counts in both the index and supplemental areas, such that:

escapement in the supplemental area = peak visible redd count for supplemental area X (escapement in index area / peak visible redd count for index area).

If chinook salmon spawning habitat exists beyond the supplemental areas, escapement for the unsurveyed area is estimated by an expansion factor derived from surveys conducted in habitat similar to the unsurveyed area. The escapement to the unsurveyed area is estimated by:

escapement in the unsurveyed area = number of unsurveyed miles X (estimated number of redds [or fish] in surveyed areas / miles of habitat surveyed).

In many of the cases where expansion factors for available habitat are used, past survey information is examined to ensure that the spawning habitat quality (based upon fish/mile or redds/mile) is similar to the area expanded. However, sometimes such data are not available. Once the escapement numbers are calculated for the index areas, each supplemental area, and any unsurveyed areas, they are summed to provide an escapement estimate for the entire system.

In systems where no weekly counts of new redds are conducted, but visible redds are recorded, escapement estimates are often derived by calculating the area under the curve for the redd counts over time. A curve is plotted with the number of visible redds on the Y-axis versus the survey date on the X-axis. The curve is plotted point to point and the area contained under the curve is used to estimate the number of redd days. Escapement estimates are then derived as follows:

total season redds = estimated number of redd days / 21-day visible redd life, and

total number of adults = total season redds X (2.5 adults/redd).

The 21-day redd life for chinook salmon is the mean number of days a given redd was visible in the Skagit River system (Orrell 1976). If the data are obtained by aerial survey, it is assumed that 5% of the redds counted are false redds and the escapement number is multiplied by 0.95 (Ames and Phinney 1977). Visibility conditions are also considered and adjustments made when survey conditions are significantly less than optimal.

In streams where it is not feasible to count redds due to either visibility problems or redd construction by other salmonid species, fish counts (live, dead, and total) are used to estimate escapement. If live counts are available on a weekly basis in a given area, a live-count curve is constructed for area-under-the-curve integration. In this case, number of live fish is plotted on the Y-axis against survey date on the X-axis. The area-under-the-curve calculation provides the number of fish days. Number of fish days is divided by 10, an estimate of the average number of days a salmon remains in a spawning area (WDFW convention), giving an escapement estimate for the area.

For smaller, less productive streams or incomplete survey data, the peak live count is related to that of a well-established area, such as the index area of Newaukum Creek. The relationship used is as follows:

estimated escapement = peak live count for area in question X (escapement of Newaukum index / peak live count for Newaukum index).

If live counts are unavailable, a similar relationship is used with dead counts such that:

estimated escapement = peak dead count in area X (escapement in established area / peak dead count in established area).

However, dead counts are used only as a last alternative since they are subject to a serious negative bias when carcasses are washed out of the system or removed by predators.

Two additional methods are used when better data are lacking: cumulative carcass counts and cumulative dead plus last-day live count. Cumulative carcass counts provide a conservative estimate and can significantly underestimate the escapement in areas where carcass flushing is high. Positive bias can also occur if surveyors neglect to mark all of the carcasses on each visit in systems using cumulative dead counts. Cumulative dead plus number of live on the last survey day also provides a conservative estimate. This method is used sparingly and only if the last survey day is near the end of the season.

In cases where few or no surveys are conducted due to adverse water conditions, estimates are made by either relating past hatchery-to-natural escapement ratios, if a hatchery is located on the river in question, or by relating visible redds to escapements at a given date in past years. In the first case, correlations or proportions of hatchery escapement to natural escapement in past years are used to estimate the natural escapement in the current year (see McAllister Creek).

In the second case, visible redds are plotted against survey date for several recent years. Since only one survey was done in 1991 on the Elwha River, the number of visible redds at that date for past years was interpolated from a graph. The number of visible redds at that date was then divided by total escapement for each year and used as follows:

total escapement = the number of visible redds in 1991 on day i X (average escapement for the past years / average number of visible redds on day i).

RESULTS

The results for each drainage are described using data from 1991 to illustrate the typical method for estimating escapement in that drainage.

Hoko River

The Makah Tribe and WDFW conducted surveys using cumulative redd counts for river miles 1.5 to 20.0, the entire range of available habitat for 1991. A sandy, muddy slough exists from river miles 0.0 to 1.5 that is unsuitable for spawning. Brownes Creek, a tributary to the Hoko River, was also surveyed for cumulative redds. For river miles 1.5 to 20.0, 347 cumulative redds were counted. This was multiplied by 2.5 adults/redd for an estimated escapement of 868 adults (Table 1). For Brownes Creek, 10 cumulative redds were counted. This was multiplied by 2.5 adults/redd for an estimated escapement of 25 adults. One redd was counted on the Sekiu River for an estimated 2.5 adults. In addition, 112 adults were removed from the Hoko River for hatchery broodstock. Total escapement to the system is estimated at *868 + 25 + 3 + 112 = 1,008* chinook salmon (Table 1).

Elwha River

The preferred method of estimating the escapement to the Elwha River is by plotting visible redds versus date and calculating the area under the curve. The area-under-the-curve integration results in the number of redd days. The number of redd days is divided by a 21-day redd life to estimate the total number of redds for the season. Total redds is multiplied by 2.5 fish/redd to estimate the escapement for the area.

Flooding river conditions prevented weekly surveys in 1991. WDFW conducted one survey on 10/10/91, covering river miles 0.2 to 4.8. Data on visible redds for the index area (RM 3.2 to 4.4) were plotted by date for 1986-1990 (Figure 2). Adequate data were collected for three of these years (1986, 1987, 1989) to interpolate visible redd values for the date of 10/10 (see arrow on Figure 2). These visible redd values were divided by the total escapement for that particular year and averaged. The mean was 0.0836. The number of visible redds for the index in 1991 was then divided by 0.0836 to provide an escapement estimate of 1,567 adults with 95% confidence limits of 1,362-1,845. The number of broodstock gaffed (857) and number of fish placed upstream at the hatchery (75) were added to this estimate for a total of 2,499 adult natural spawners in 1991. The ratios of hatchery to natural escapement in the Elwha River were investigated as another possible way to estimate natural escapement for 1991, but the ratios showed high annual variability.

Table 1. Hoko River chinook salmon escapement estimate – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live	Dead	Total	New Redds	Visible Redds	Cumul. Redds	Season Cumul. Redds	Estimated Escapement
9/24/91	1.5	3.4	0	0	0	1	1	1		
9/30/91	1.5	3.4	60	0	60	1	2	2		
10/04/91	1.5	3.4	0	0	0	3	5	5		
10/07/91	1.5	3.4	16	1	17	4	7	9		
10/11/91	1.5	3.4	0	0	0	1	8	10		
10/18/91	1.5	3.4	0	2	2	5	10	15		
10/25/91	1.5	3.4	14	0	14	5	17	20		
10/31/91	1.5	3.4	0	0	0	1	17	21		
11/10/91	1.5	3.4	1	1	2	2	10	23	23	58
9/24/91	3.4	5.6	0	0	0	0	0	0		
9/30/91	3.4	5.6	1	0	1	1	1	1		
10/04/91	3.4	5.6	1	0	1	6	7	7		
10/07/91	3.4	5.6	8	0	8	8	12	15		
10/11/91	3.4	5.6	7	1	8	6	17	21		
10/18/91	3.4	5.6	35	2	37	33	49	54		
10/25/91	3.4	5.6	69	8	77	38	86	92		
10/31/91	3.4	5.6	23	9	32	14	97	106		
11/10/91	3.4	5.6	16	4	20	17	82	123	123	308
9/24/91	5.6	8.4	2	1	3	3	3	3		
10/04/91	5.6	8.4	7	2	9	2	5	5		
10/11/91	5.6	8.4	11	0	11	20	25	25		
10/18/91	5.6	8.4	18	0	18	16	39	41		
10/25/91	5.6	8.4	17	0	17	7	44	48		
10/30/91	5.6	8.4	9	4	13	14	57	62		
11/09/91	5.6	8.4	65	6	71	41	85	103	103	258
9/24/91	9.5	10.0	0	0	0	0	0	0		
10/04/91	9.5	10.0	2	0	2	6	6	6		
10/12/91	8.4	10.2	11	19	30	12	17	18		
10/18/91	8.4	10.2	28	3	31	9	27	27		
10/25/91	8.4	10.2	10	4	14	9	37	36		
10/30/91	8.4	10.2	5	4	9	4	40	40		
11/08/91	8.4	10.2	90	4	94	45	60	85	85	212
Season	10.2	11.0	8	0	8	6	6	6	6	15
Season	13.0	15.3	1	1	2	6	6	6	6	15
Season	15.3	20.0	0	0	0	1	1	1	1	3
Season Brownes Cr.	0.0	0.7	11	4	15	10	10	10	10	25
Season Sekiu R.	0.7	5.3	0	0	0	1	1	1	1	3
Total									358	896

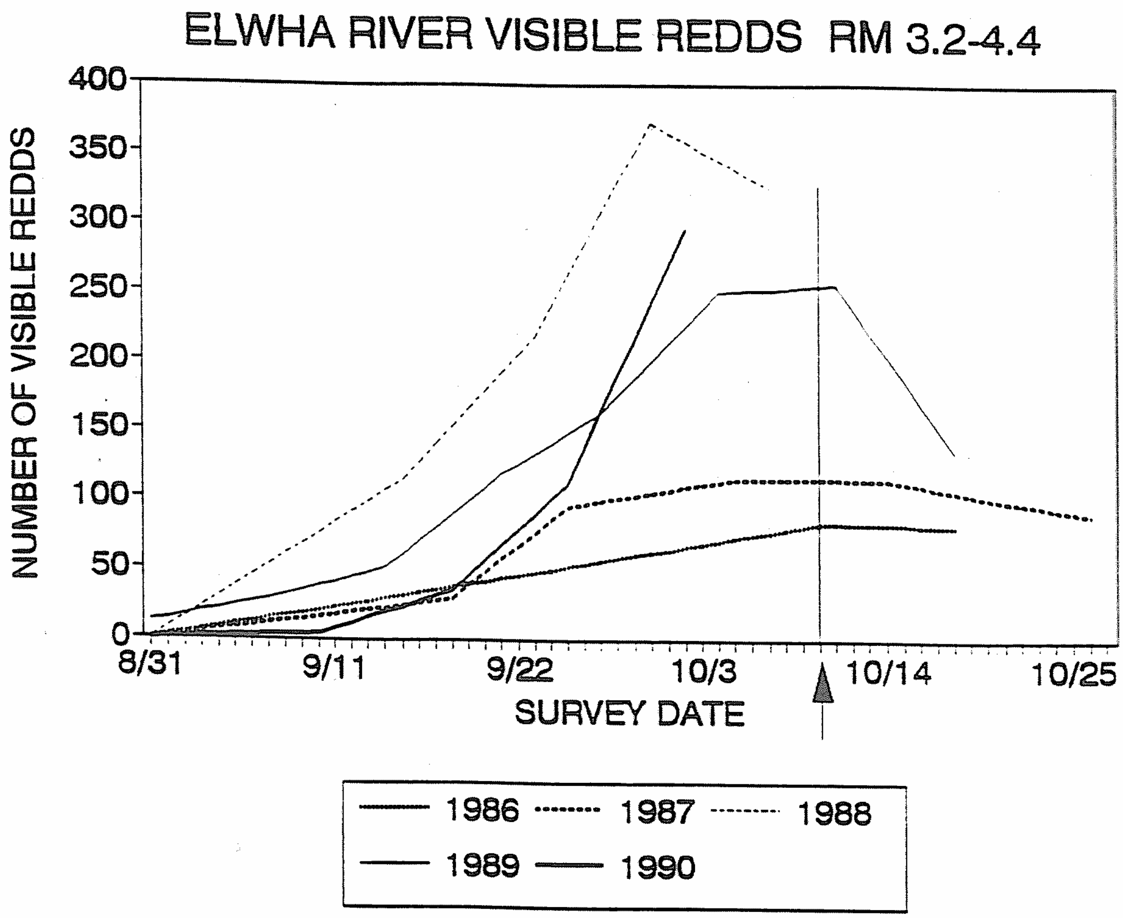

Figure 2. Number of visible redds versus survey date for the Elwha River, 1986 to 1990. Because of adverse river conditions in 1991, only one chinook salmon spawning ground survey was conducted on 10/10. Escapement was estimated by relating the number of visible redds counted on that date in 1991 (arrow) to the escapement / visible redds counted in earlier years.

Dungeness River

Since 1986, complete cumulative redd count surveys have been conducted from early August to late October covering all of the spawning habitat (RM 0.0 to 18.7). Cumulative redds (63) in 1991 were counted and multiplied by 2.5 adults/redd for an escapement estimate of 158 adults for the Dungeness River (Table 2). Similar methods were used for the Grey Wolf River, a tributary to the Dungeness River, where two redds were counted. For the entire Dungeness system in 1991, 65 cumulative redds were counted for an escapement estimate of 163 adults.

Nooksack River System

The Nooksack River system is very difficult to accurately survey due to frequently turbid water conditions. Past estimates of summer/fall natural spawners have used the method described by Ames and Phinney (1977) in which the Nooksack escapement is assumed to be 15.6% of the Skagit escapement based upon average escapement estimates from 1965-1974. However, the few survey results that we have obtained suggest that this relationship no longer adequately approximates the Nooksack escapement, but greatly overestimates it. Efforts are underway to resume more thorough surveys and develop a system-specific estimate.

Spring chinook salmon in the glacial-colored North Fork Nooksack were enumerated by cumulative carcass count in known spawning areas. In 1991, 31 carcasses were counted (Table 3). This can be compared to similar counts made since 1985 when divided by survey effort (which increased in 1991).

Spring chinook salmon in the South Fork Nooksack were estimated by multiplying the number of visible redds from a helicopter survey on 9/23/91 by *(cumulative redds / visible redds recorded on similar dates in 1988-1990)*. The estimate for 1991 was 365 natural spawners (Table 4). In most years, cumulative redds are counted in each of the five reaches to derive an escapement estimate, but river conditions prevented accurate redd counts throughout the spawning season in 1991.

Samish River

The preferred method, when visibility permits, is to estimate escapements from redd counts, using peak visible redd counts as the estimator after weekly surveys are conducted. In 1991, the peak number of visible redds was 214 (Table 5). The number of redds was multiplied by 0.95 true redds and by 2.5 fish/redd to provide an estimate of 508 fish. When river conditions hamper redd counting, cumulative new carcass counts are used. The river is surveyed by foot on a weekly basis with carcasses counted and marked by caudal fin cuts.

Table 2. Dungeness River chinook salmon escapement estimate – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	New Redds	Cumulative Redds
8/07/91	15.8	17.5	0	0	0	0
8/07/91	17.5	18.7	0	0	0	0
8/14/91	15.8	17.5	0	0	0	0
8/15/91	6.4	9.2	2	0	1	1
8/15/91	9.2	10.8	0	0	1	2
8/20/91	10.8	13.8	2	0	1	3
8/20/91	13.8	15.8	0	0	2	5
8/21/91	15.8	17.5	0	0	0	5
8/21/91	17.5	18.7	0	0	1	6
8/22/91	7.3	9.2	0	0	1	7
8/22/91	9.2	10.8	0	0	2	9
8/23/91	6.4	7.3	0	0	2	11
8/26/91	10.8	13.8	2	0	2	13
8/26/91	13.8	15.8	3	0	3	16
8/27/91	9.2	10.8	0	0	2	18
8/28/91	15.8	17.5	0	0	1	19
8/28/91	17.5	18.7	0	0	1	20
9/03/91	0.0	3.3	0	0	1	21
9/03/91	3.3	6.4	0	1	0	21
9/03/91	6.4	7.3	1	0	2	23
9/04/91	10.8	13.8	4	2	2	25
9/04/91	13.8	15.8	1	0	1	26
9/05/91	15.8	17.5	0	0	0	26
9/05/91	17.5	18.7	0	0	0	26
9/06/91	7.3	10.8	2	2	3	29
9/09/91	0.0	3.3	1	0	5	34
9/09/91	3.3	6.4	0	0	0	34
9/09/91	6.4	7.3	8	0	3	37
9/10/91	10.8	13.8	0	0	0	37
9/10/91	13.8	15.8	0	0	0	37
9/11/91	15.8	17.5	0	0	0	37
9/12/91	9.2	10.8	0	3	1	38
9/12/91	17.5	18.7	0	0	0	38
9/13/91	7.3	9.2	1	2	2	40
9/16/91	3.3	6.4	1	2	3	43
9/16/91	6.4	7.3	0	0	0	43
9/17/91	0.0	3.3	2	2	4	47
9/17/91	9.2	10.8	0	1	0	47
9/19/91	10.8	13.8	0	1	0	47
9/19/91	13.8	15.8	0	0	0	47
9/20/91	7.3	9.2	0	2	0	47
9/20/91	15.8	17.5	0	1	0	47
9/20/91	17.5	18.7	0	0	0	47
9/23/91	3.3	6.4	7	2	5	52
9/23/91	6.4	7.3	0	0	0	52
9/24/91	0.0	3.3	2	4	2	54
9/24/91	9.2	10.8	0	0	0	54
9/26/91	10.8	13.8	0	0	0	54
9/26/91	13.8	15.8	0	0	0	54
9/27/91	7.3	9.2	0	2	0	54
9/30/91	3.3	6.4	3	1	3	57
9/30/91	6.4	7.3	0	0	1	58
10/01/91	0.0	3.3	1	1	2	60
10/07/91	0.0	1.9	0	0	1	61
10/07/91	1.9	3.3	0	0	2	63
10/14/91	0.0	3.3	0	0	0	63
10/21/91	0.0	3.3	0	0	0	63

Table 3. North Fork Nooksack River cumulative chinook salmon carcass counts, 1985 – 1991.

Year	Number of Carcasses	River Miles Surveyed	Carcasses/River Mile Surveyed
1985	69	28	2.46
1986	74	28	2.64
1987	40	28	1.43
1988	66	28	2.36
1989	18	28	0.64
1990	1	28	0.04
1991	31	63.7	0.49

Table 4. South Fork Nooksack River chinook salmon escapement estimate – 1991.

River Section	1988-90 Average Cum. Redds/ Visible Redds	1991 Visible Redds	1991 Projected Cumulative Redds
Reach 1	2.15	7	15
Reach 2	2.36	18	42
Reaches 3, 4, 5	1.15	84	97
Total estimated cumulative redds = 154			
Escapement = cumulative redds X (% true redds) X (fish/redd) = 365			
Assumed 95% true redds and 2.5 fish/redd			

Table 5. Samish River chinook salmon redd counts – 1991.

Survey Date	Lower River Mile	Upper River Mile	Redd Count
9/21/91	8.2	10.5	22
9/30/91	8.2	10.5	63
10/07/91	8.2	10.5	121
10/15/91	8.2	10.5	214
10/23/91	8.2	10.5	132

Skagit River System

The entire mainstem of the Skagit River and known spawning areas in the Sauk and Cascade Rivers are surveyed by helicopter on either a weekly (odd years) or biweekly (even years) schedule. In odd years, the aerial surveys are concentrated in the first half of the run with a straight line connecting the peak to the end of redd visibility. This is due to large numbers of pink salmon (*O. gorbuscha*) spawning in the same area as the chinook salmon.

Earlier spawners (spring run) are located in the upper Sauk River, Suiattle River, and upper Cascade River. Later spawners (summer/fall run) typically spawn in the Skagit River mainstem, its associated tributaries, and the lower Sauk River. For most of these runs, escapement is estimated using the same methods with the results separated by location.

Index areas are also surveyed by foot on the same day as the aerial surveys to estimate the percentage of redds overlooked by the aerial surveys. Comparisons are made between the data from the foot surveys and aerial surveys, with the ratio between the two used as an expansion factor to adjust the aerial survey data for the non-index sections. The number of visible redds is plotted against survey date, with the peak of the redd curve based upon data from extensive surveys in the base year of 1973 (Orrell 1976). Cumulative redds are estimated from the graphs by obtaining the number of redds at 21-day intervals and summing these 21-day interval redd counts for the season (Figures 3, 4, 5, 6, and 7).

Escapement into Suiattle River is estimated by dividing the peak live and dead count by river miles surveyed in each of four index areas of Big, Tenas, Buck, and Sulphur Creeks. This results in fish/mile estimates which are averaged and multiplied by the total available spawning habitat estimate of 8.5 miles (Orrell 1976). In 1991, the fish/mile estimates for Big, Tenas, Buck, and Sulphur Creeks were 1.7, 6.7, 55.0, and 103.3, respectively. The average fish/mile estimate, 41.7, was multiplied by 8.5 miles for a final estimate of 354 adult chinook salmon spawners for the Suiattle River.

Escapements to smaller tributaries were estimated by multiplying the peak redd count (total = 80 in 1991) by 0.95 true redds and by 2.5 fish/redd (Table 6). These tributaries included: Finney Creek, Day Creek, Illabot Creek, Diobsud Creek, Bacon Creek, Goodell Creek, Clark Creek, and Falls Creek. An additional 169 chinook salmon were counted at the Baker River trap.

The total Skagit River system summer/fall chinook salmon escapement estimate for 1991 was 6,014 fish, which included 5,655 fish estimated from the graphically-derived cumulative redds using the mainstem Skagit, Sauk, and Cascade River data; 190 fish calculated from the peak redd counts of the tributaries; and 169 fish from the Baker River trap. Total spring chinook salmon escapement was estimated as 1,411 fish in 1991. This included 354 fish in the Suiattle River, 747 in the upper Sauk River, and 310 in the upper Cascade River.

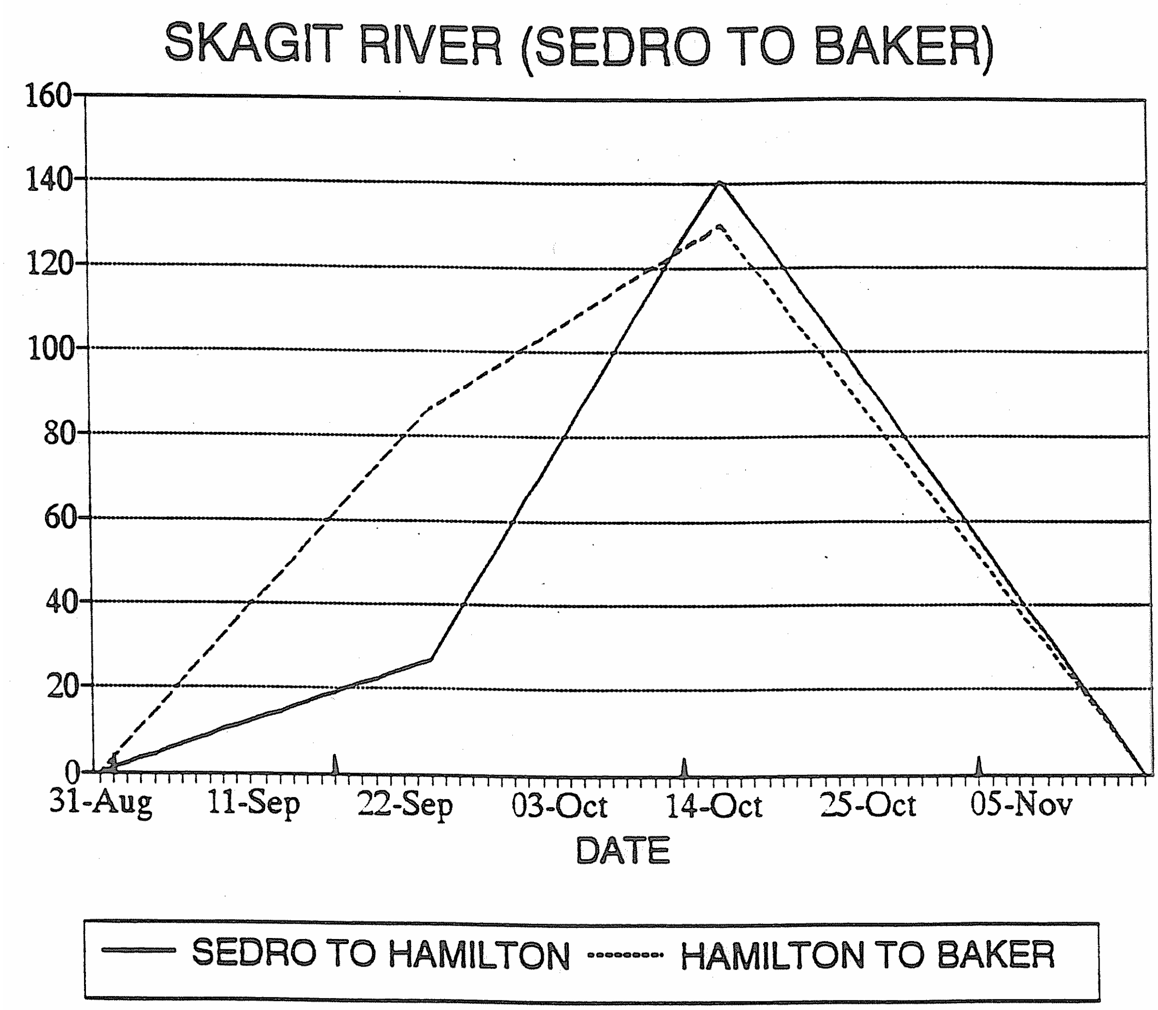

Figure 3. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). These data represent surveys in the Skagit River from Sedro Wooley to the Baker River.

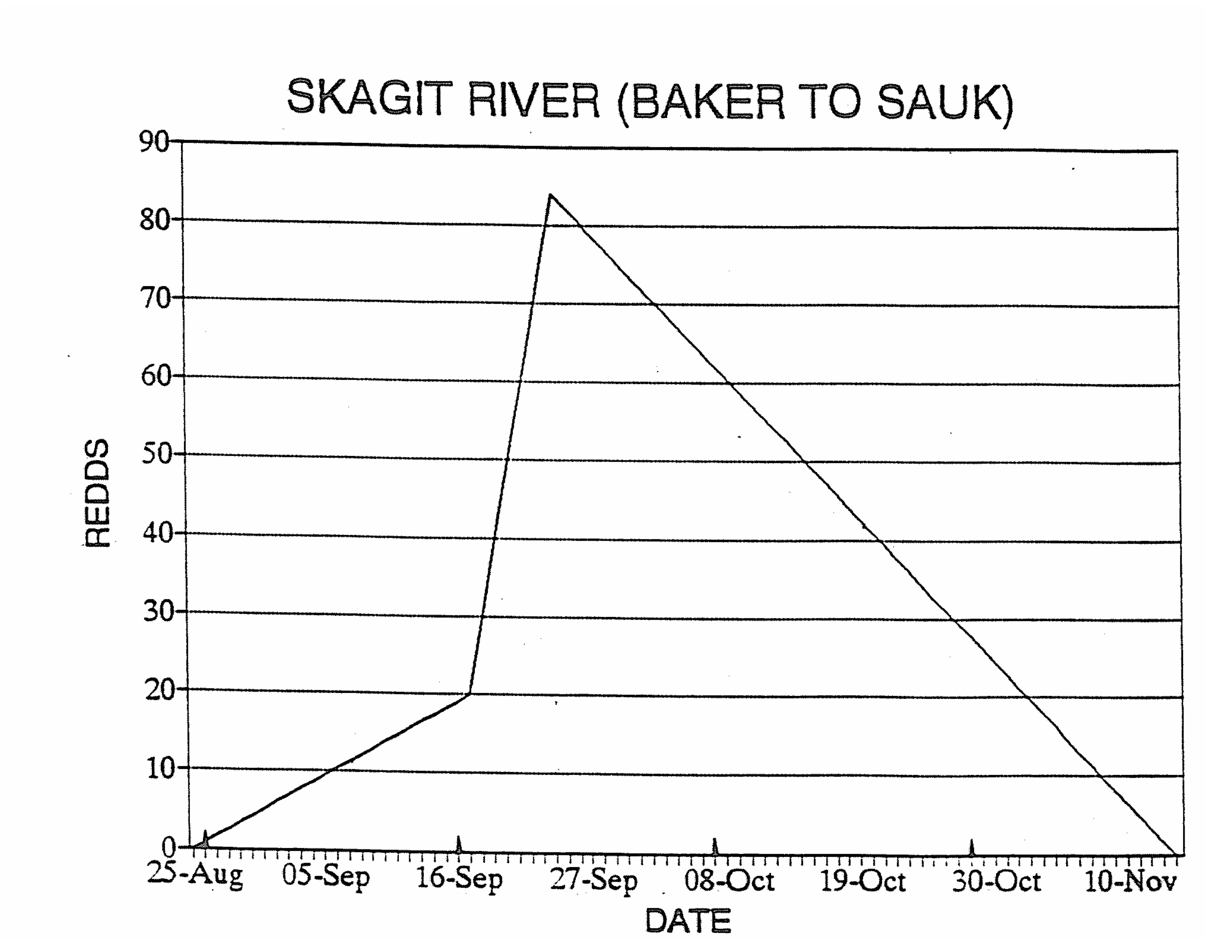

Figure 4. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). These data represent surveys in the Skagit River from the Baker River to the Sauk River.

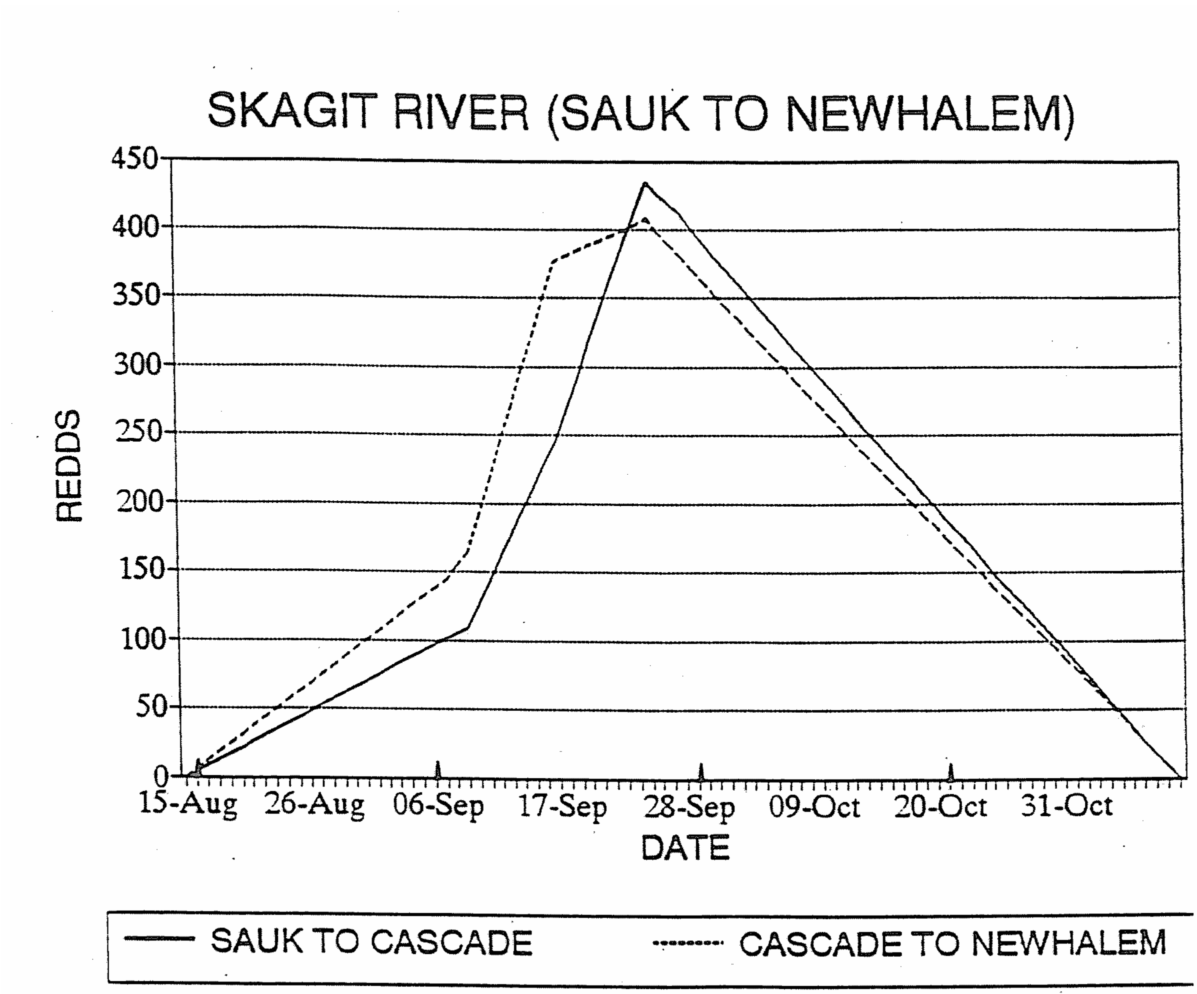

Figure 5. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). These data represent surveys in the Skagit River from the Sauk River to Newhalem.

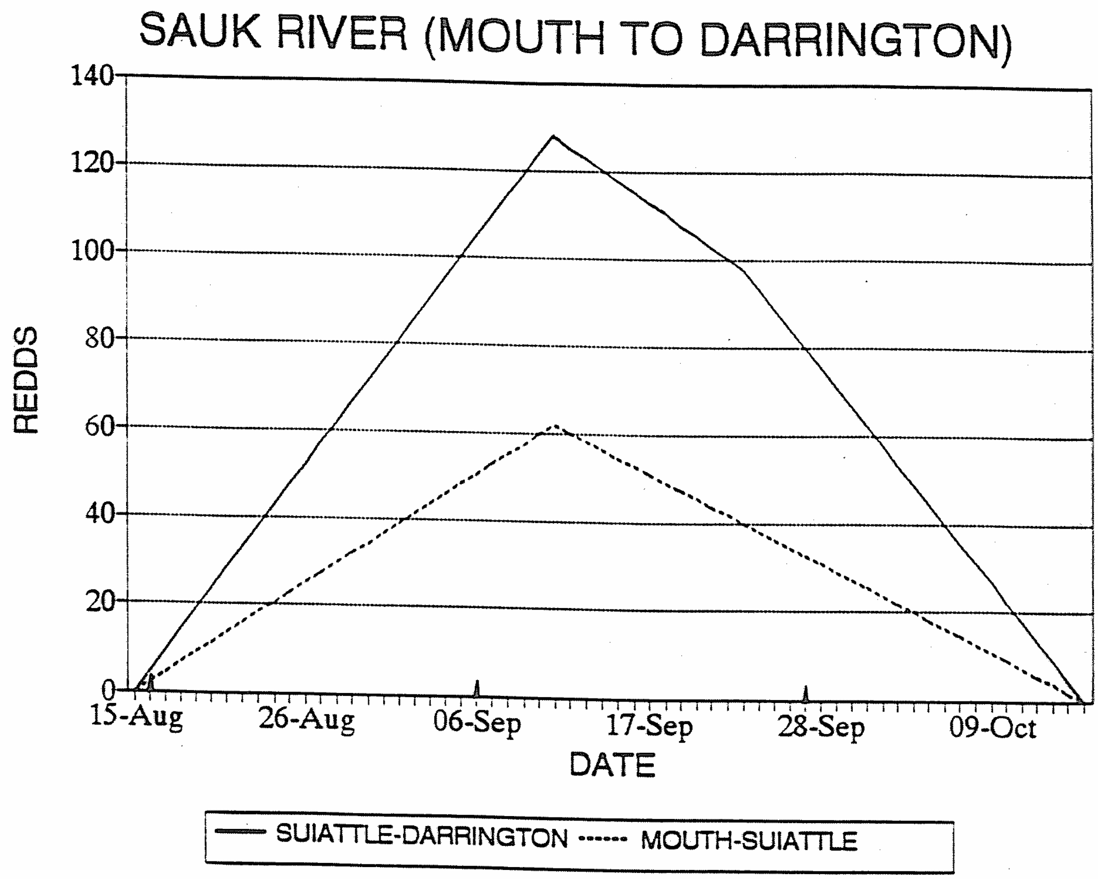

Figure 6. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). Surveyed area was in the Sauk River from the mouth to Darrington.

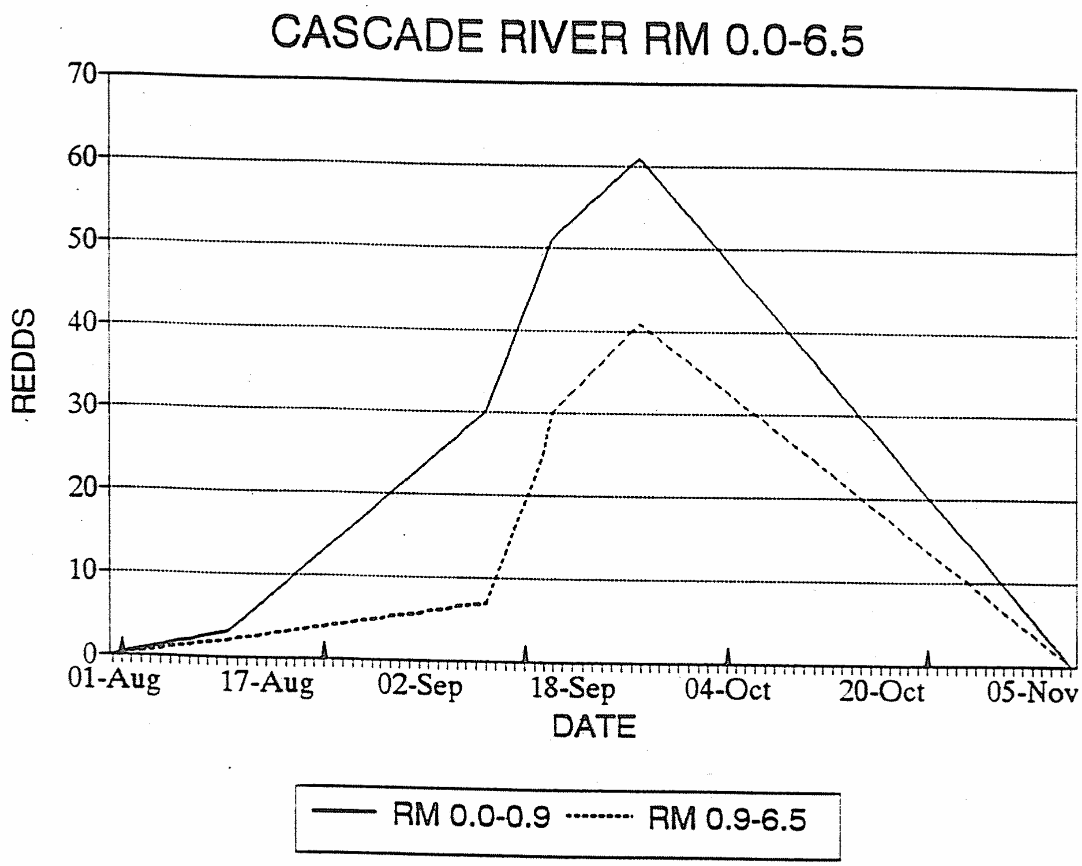

Figure 7. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). Surveyed area was in the Cascade River from river miles 0.0 to 6.5.

Table 6. Skagit River tributary peak counts of chinook salmon redds – 1991.

Stream Survey Date	Lower River Mile	Upper River Mile	Peak Redd Count
Finney Creek 10/02/91	0.0	4.1	13
Day Creek 10/08/91	0.0	2.2	13
Illabot Creek 9/09/91	0.0	1.9	16
Diobsud Creek 9/11/91	0.0	1.1	2
Bacon Creek 9/17/91	0.0	8.0	19
Goodell Creek 9/11/91 9/17/91	 0.0 0.7	 0.7 6.0	 4 1
Clark Creek 9/05/91	0.0	0.1	2
Falls Creek 9/18/91	0.0	0.2	10
Total			80

Stillaguamish River System

The escapement to the Stillaguamish River system was estimated using the same methods as the Skagit River. The total estimated escapement for the Stillaguamish River was 1,536 adults, with 1,409 fish estimated in the mainstem and North Fork by cumulative redds derived from graphs of visible redds versus survey date (Figures 8, 9, and 10). The South Fork estimate was 50 fish based upon a peak redd count of 20. Boulder River and Squire Creek had peak redd counts of 8 and 18, respectively, which were multiplied by 2.5 fish/redd for an estimate of 65 fish. Jim Creek was estimated using the peak total fish count of 12 live plus dead fish.

Snohomish River System

The Snohomish River system (without the Snoqualmie River) escapement estimate was 2,155 fish. The Skykomish mainstem and South Fork Skykomish to Sunset Falls escapement was calculated using cumulative redd curves as described for the Skagit River system. These curves provided an estimate of 1,215 fish for both of the areas (Figures 11 and 12). The mainstem Snohomish River was difficult to survey in 1991 due to the presence of large numbers of pink salmon. The estimate was based upon the following calculation: *(visible redds on 9/18/90 / 1990 escapement) = (visible redds on 9/17/91 / 1991 escapement) = 42 fish*. The South Fork Skykomish River above Sunset Falls escapement was the number of adults (415) trucked to that area. The Sultan River escapement was estimated by a cumulative redd count of 99 redds to provide an escapement of 235 fish *(99 redds X 2.5 adults/redd X 95% true redds)*. The Wallace River escapement of 200 fish was estimated by cumulative carcass counts (Table 7).

Table 7. Wallace River chinook salmon carcass counts – 1991.

Survey Date	Lower River Mile	Upper River Mile	Dead Adults
9/23/91	0.0	4.2	1
9/30/91	0.0	4.2	45
10/08/91	0.0	4.2	81
10/15/91	0.0	4.2	72
10/29/91	0.0	4.2	1
Total			200

The Snoqualmie River escapement was derived from aerial survey data unsupplemented with foot survey data. The estimate was based upon 10.1 miles of index area out of a total 39.6 miles of river below Snoqualmie Falls. The index areas were chosen to represent greater concentrations of spawners. Visible redds were counted throughout the first half of the known run timing and plotted against survey date. Typically, a plateau exists in the first half of the redd curve for the Snoqualmie River (Figure 13). The area under the curve was estimated as 4,569 redd days. This redd-day value was divided by the 21-day redd survey life for an estimate of 218 redds for the season total. This was multiplied by 0.95 for true redds and by 2.5 adults/redd for an escapement estimate of 517 adults. No expansion factor was used to account for unsurveyed areas.

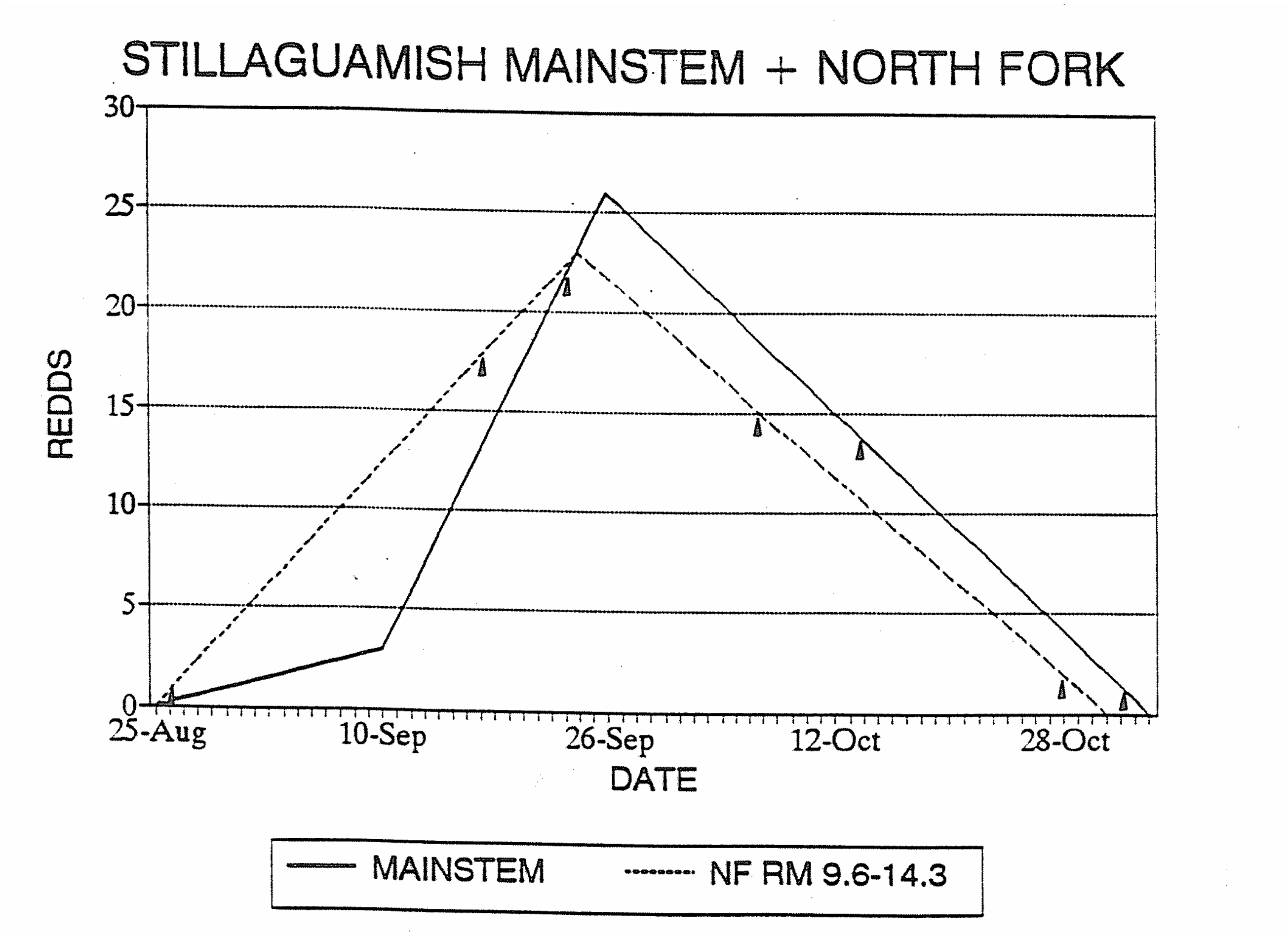

Figure 8. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). This graph represents surveys in the Stillaguamish mainstem and North Fork Stillaguamish river miles 9.6 to 14.3.

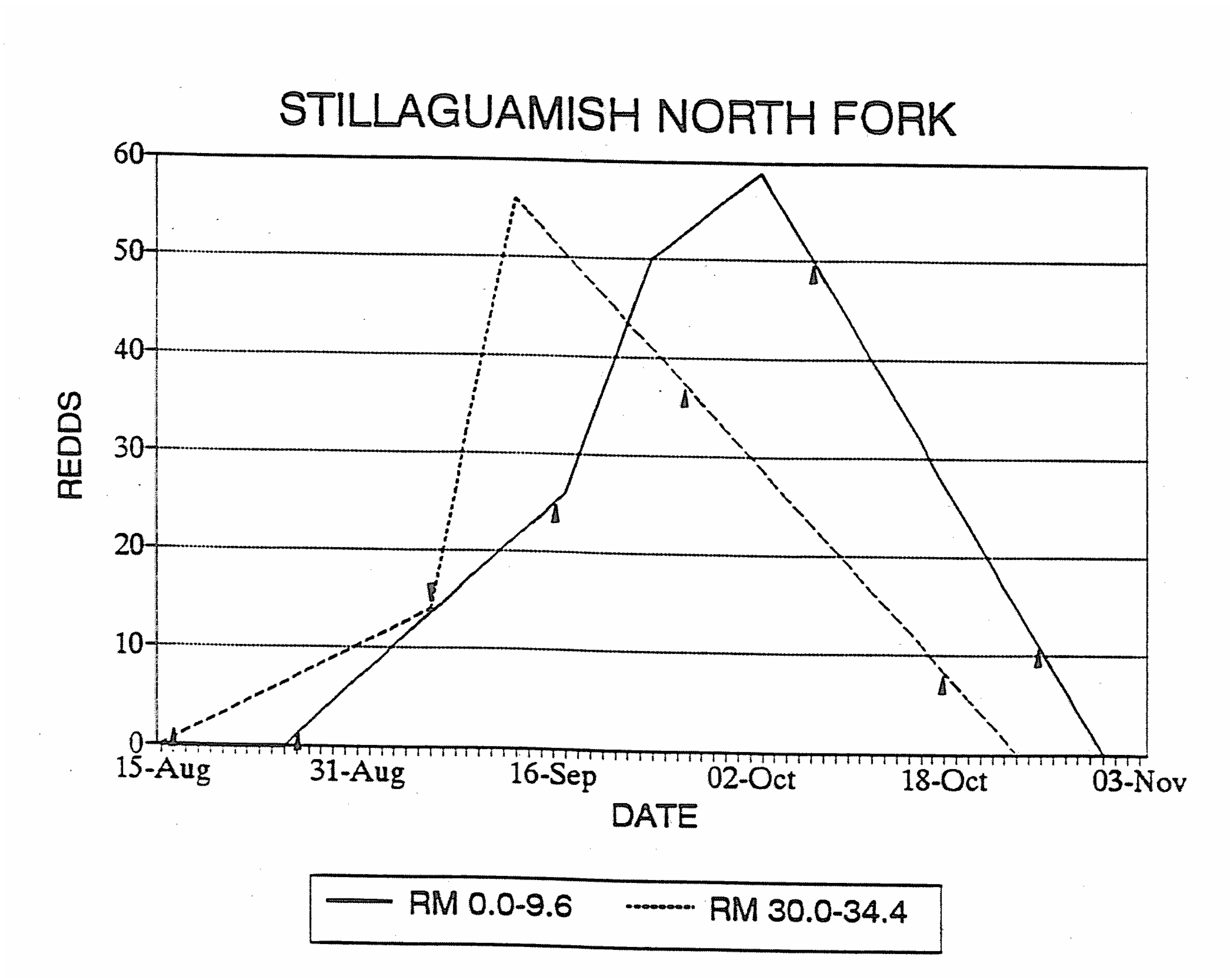

Figure 9. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). This graph represents surveys in the North Fork Stillaguamish river miles 0.0 to 9.6 and river miles to 30.0 to 34.4.

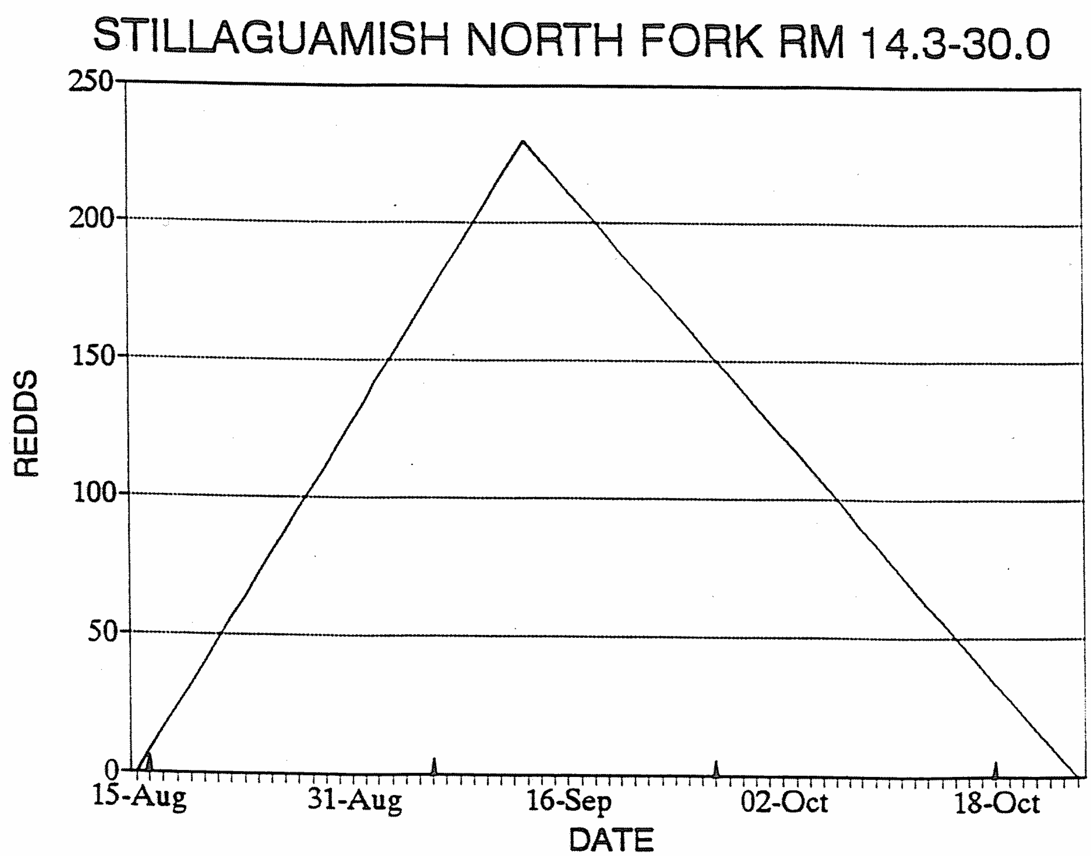

Figure 10. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). This graph represents surveys in the North Fork Stillaguamish river miles 14.3 to 30.0.

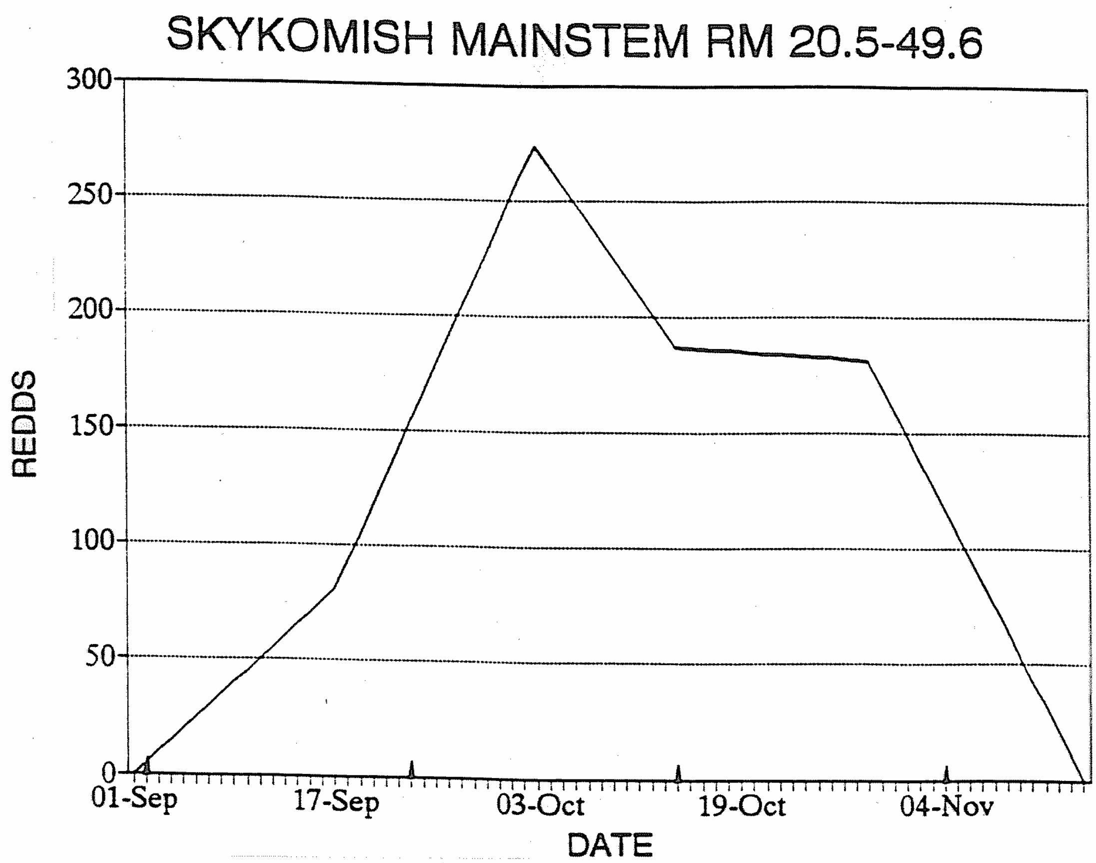

Figure 11. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). These data were from the Skykomish River mainstem river miles 20.5 to 49.6.

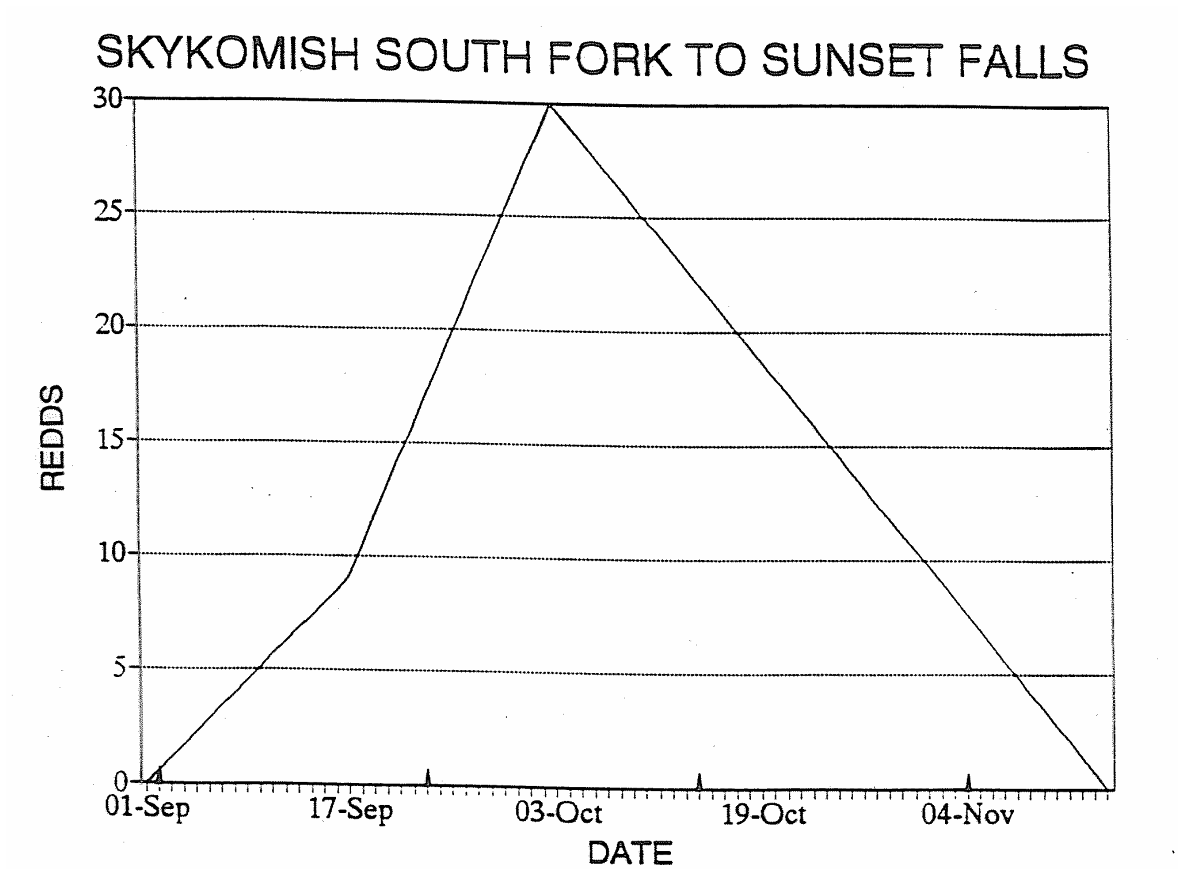

Figure 12. Visible redd curve used to estimate cumulative redds by summing interpolated redd counts at 21-day intervals (arrows). These data were from the Skykomish River from the forks to Sunset Falls.

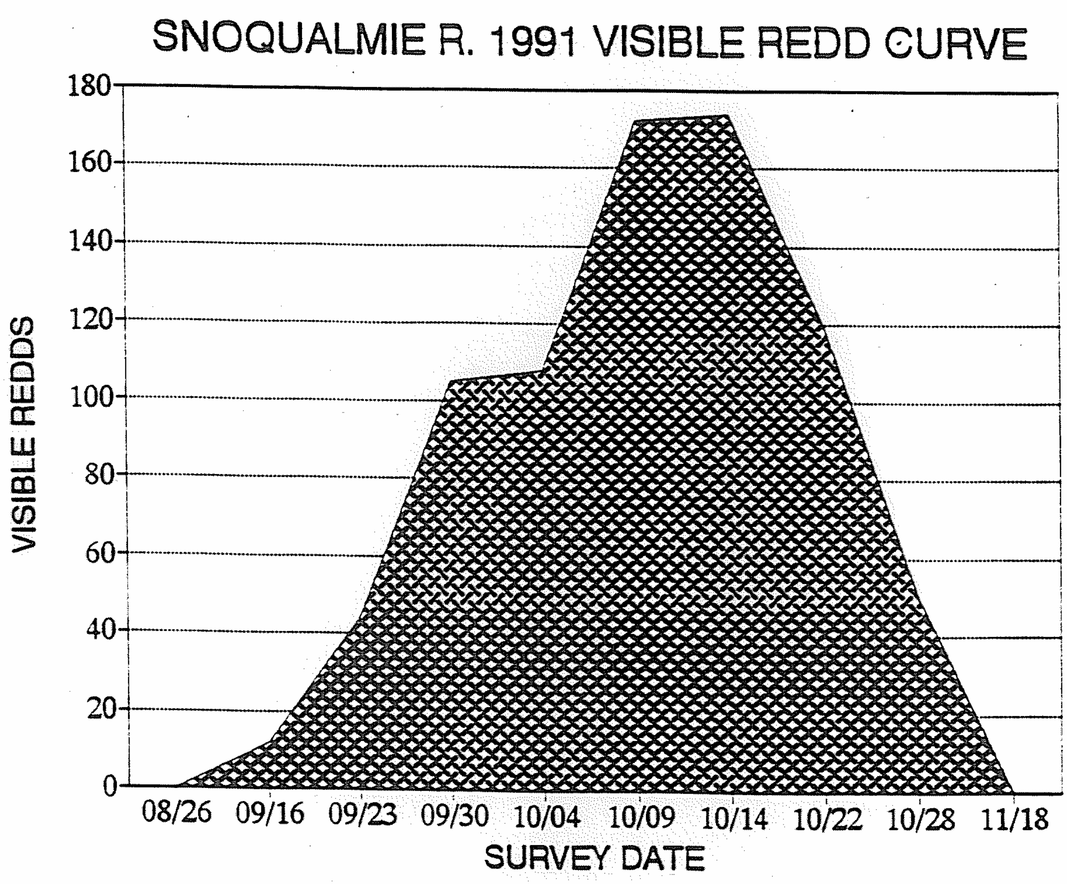

Figure 13. Number of visible chinook salmon redds by survey date in the Snoqualmie River plotted for area-under-the-curve analysis.

Tributaries of the Snoqualmie River which have chinook salmon spawning habitat are the Tolt River, Raging River, and Tokul River. The Tolt River escapement was calculated by: *Tolt peak visible redd count X (Snoqualmie escapement / Snoqualmie peak visible redd count) = 29 X (517 / 174) = 86 fish.* South Fork Tolt surveys recorded only 5 redds. This was multiplied by 2.5 adults/redd for an estimated 13 fish. Four redds were recorded in the Raging River near the end of the season (11/01/91). This was multiplied by *(Snoqualmie escapement / Snoqualmie peak visible redd count)* for an estimate of 12 adults. Total escapement for the Snoqualmie River and its tributaries was estimated as *517 + 86 + 13 + 12 = 628 chinook salmon*. This estimate was included in the total escapement for the Snohomish system of 2,783 fish. Escapement surveys for chinook salmon were not conducted in the Tokul River in 1991.

Lake Washington System

The Cedar River was surveyed for live and dead chinook salmon. A spawner curve of live counts versus survey date was plotted, point to point, and the area under the curve calculated (Figure 14). The estimated number of fish days (6,138) was divided by the 10-day assumed residence time for an escapement estimate of 614 adults. The curve had an unusual bimodal distribution in 1991 that was probably due to salmon holding in the lake until additional rain fell.

The only complete data set available for Issaquah Creek contained dead counts (Table 8). The escapement estimate was calculated as the sum of the individual carcass counts for the season plus the live count from the last survey day: *749 + 310 = 1,059 fish.*

Data from the East Fork Issaquah Creek were sparse and it was questionable whether the recorded peak was representative of the actual peak. The East Fork Issaquah Creek escapement was estimated as: *total fish on first survey + number of live fish in subsequent surveys with more than a 10-day interval between surveys* (Table 8). The 10-day interval was based upon the 10-day residence time used for spawner-curve analysis. This resulted in an escapement estimate of 8 fish. This estimate was added to the estimate of 1,059 for Issaquah Creek for a total escapement estimate of 1,067 adult chinook salmon.

Escapements for Bear Creek and Cottage Lake Creek were calculated using the escapement estimate for the Newaukum Creek index, an area more extensively surveyed in 1991. For Bear Creek, the peak dead count was 22 fish on 10/30/91 (Table 9). This peak dead count was multiplied by *(Newaukum index escapement / Newaukum index peak dead count) = 22 X (183 / 54) = 75 fish.*

Cottage Lake Creek escapement was estimated by first calculating the live fish/total fish ratio for the peak live count, which was *(58 / 81) = 0.716* (Table 9). This ratio was used to determine which day of the Newaukum run was best to choose for Newaukum projected live counts (i.e., the day when the live to total ratios were equal). Projected (interpolated) live count at the Newaukum Creek index for a similar point in the run distribution was 67 fish (Table 12). The escapement to Cottage Lake Creek was calculated as: *peak live count at Cottage Lake Creek X (escapement for the Newaukum index / projected live count for the Newaukum index) = 58 X*

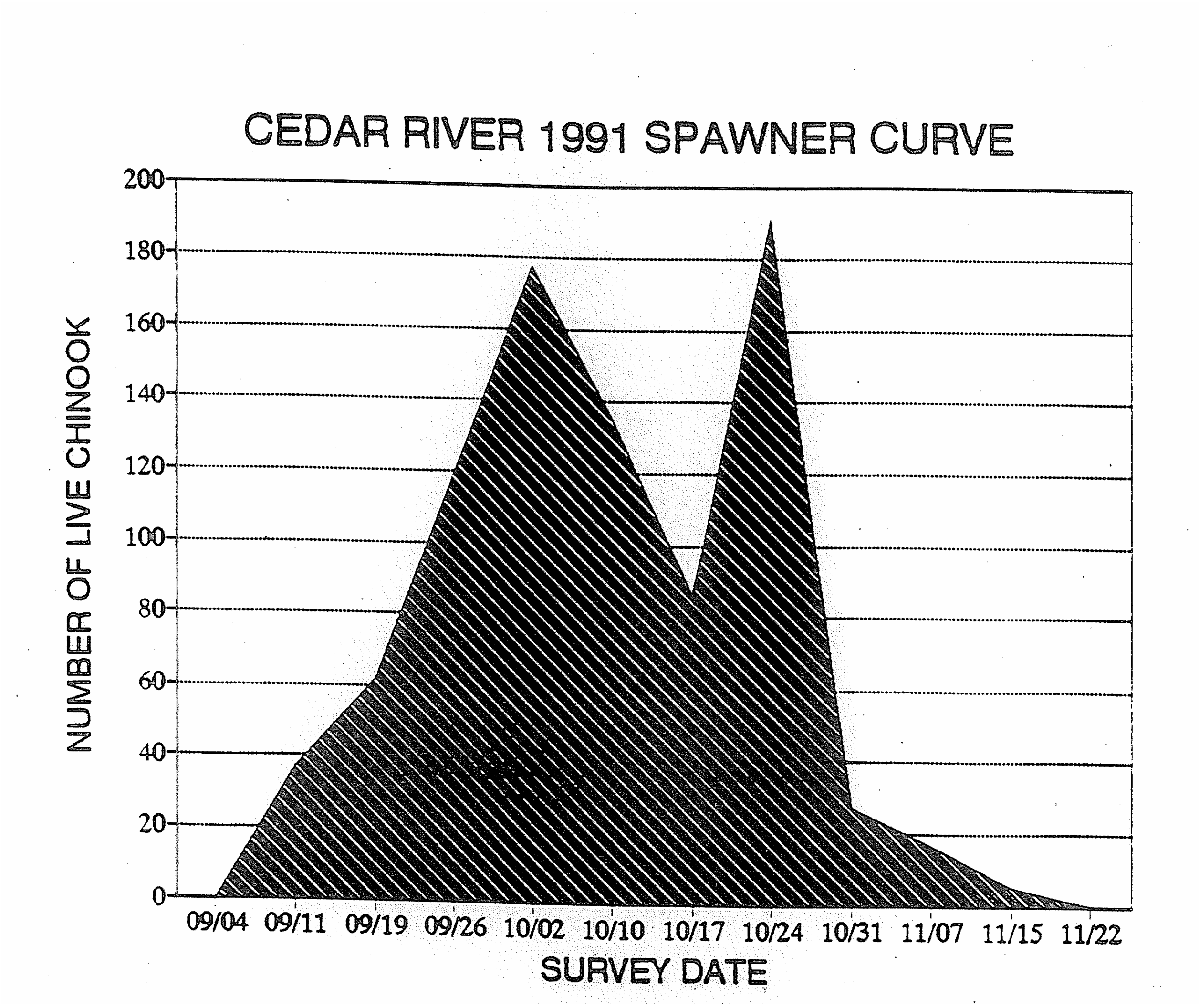

Figure 14. Number of live chinook salmon counted by survey date in the Cedar River plotted for area-under-the-curve analysis.

Table 8. Issaquah Creek and East Fork Issaquah Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
Issaquah Creek					
9/23/91	1.8	3.0	216	51	267
9/24/91	0.0	1.8	21	11	32
10/02/91	0.0	3.0	300	226	539
10/10/91	0.0	3.0	NC	281	NC
10/16/91	0.0	3.0	310	180	658
East Fork Issaquah Creek					
10/30/91	0.0	3.0	3	4	7
11/14/91	0.0	3.1	0	1	1
11/25/91l	0.0	3.1	1	0	1

Table 9. Bear Creek and Cottage Lake Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
Bear Creek					
9/17/91	1.3	4.1	0	1	1
9/17/91	4.1	6.6	3	0	3
9/17/91	6.6	8.8	0	0	0
10/01/91	1.3	4.1	6	4	10
10/01/91	4.1	6.6	17	4	21
10/01/91	6.6	8.8	0	0	0
10/15/91	1.3	4.1	13	10	23
10/15/91	4.1	6.6	3	7	10
10/15/91	6.6	8.8	0	1	1
10/30/91	1.3	8.8	2	22	24
11/14/91	1.3	4.1	0	1	1
11/14/91	4.1	6.6	1	6	7
Cottage Lake Creek					
10/01/91	0.0	2.3	5	0	5
10/15/91	0.0	2.3	58	23	81
10/30/91	0.0	2.3	5	21	26

(183 / 67) = 158 adults. Escapement for miscellaneous Lake Washington streams includes estimates from Bear Creek and Cottage Lake Creek for an estimated total escapement of 233 chinook salmon.

Green River System

Escapement to the Green River system was estimated in sections. Two areas were covered by both raft and aerial surveys, with cumulative redds recorded for one area during the raft surveys. Escapement for these two areas was estimated from the raft cumulative redd count, while a comparison of the counts from the aerial and raft surveys was used to develop a correction factor for areas of the river that were surveyed only by aircraft.

A large portion of the river was surveyed using aircraft without supplementation by foot or raft surveys. Visible redds counted during the aerial surveys were adjusted using the aerial/raft correction factor calculated above. A third region of the river was not surveyed; a watershed expansion factor was used to estimate the escapement in the unsurveyed region.

Aerial surveys were used to conduct visible redd counts in river miles 29.6 - 47.0 and 56.0 - 61.0. Raft surveys were conducted on the same day in an index section (RM 41.5 - 43.0) and in a supplemental section (RM 35.0 - 41.5). Visible redds and live and dead chinook salmon were counted in both raft surveys (Table 10). New redds were recorded and flagged in the index area so that cumulative redds could be determined. Escapement was calculated in the index area by summing the new redds from each visit (83) and multiplying by 2.5 adults/redd for an estimate of 208 fish. The escapement to the supplemental area was calculated as: *peak visible redd count in the supplemental area X (escapement in index area / peak visible redd count in index area) = 330 X (207.5 / 55) = 1,245 chinook salmon.*

The peak visible redd count from the aerial surveys was compared to the peak visible redd count from the raft surveys conducted on the same day for the same area. For the index region, the peak visible redd count was 24 for the aerial survey and 55 for the raft survey. In the supplemental area, the peak visible redd count was 155 for the aerial survey and 325 for the raft survey. This resulted in a 2.19 average correction factor for the aerial surveys. Water visibility problems were the primary cause of this large expansion factor. For the remainder of the river surveyed by aircraft, the peak visible redd count was 292. This was corrected to correspond to the raft data (*292 X 2.19*) for an estimate of 640 redds for the peak visible redd count. Escapement to the area surveyed only by aircraft was estimated by: *corrected peak visible redd count X (cumulative redds in index area / peak visible redd count in index area) X (2.5 adults/redd) = 640 X (83 / 55) X 2.5 = 2,416 fish.* Total escapement in the surveyed area was the sum of the two estimates from the raft surveys and the remaining aerial survey area, *208 + 1,245 + 2,416 = 3,869 adults.* This estimate was expanded for spawning habitat available / spawning habitat surveyed: *3,869 adults X 2.6 mileage expansion factor = 10,059 total chinook salmon for the Green River estimate.*

Newaukum Creek was surveyed in two sections, the index area (RM 0.0 - 1.0) and the supplemental area (RM 1.0 - 3.9). Live adults, dead adults, and visible redds were recorded for

Table 10. Green River chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Raft: Live Adults	Raft: Dead Adults	Raft: Total Adults	Raft: New Redds	Raft: Visible Redds	Raft: Cumul. Redds	Aerial: Visible Redds
9/16/91	41.5	43.0	5	0	5	1	1	1	0
9/23/91	41.5	43.0	24	1	25	10	11	11	10
9/30/91	41.5	43.0	48	11	59	21	32	32	10
10/04/91	41.5	43.0							15
10/07/91	41.5	43.0	45	24	69	25	51	57	
10/09/91	41.5	43.0							19
10/14/91	41.5	43.0	10	18	28	16	55	73	24
10/23/91	41.5	43.0	0	19	19	10	54	83	
9/16/91	35.0	41.5	91	1	92		20		11
9/23/91	35.0	41.5	283	8	291		101		48
9/30/91	35.0	41.5	352	44	396		244		114
10/04/91	35.0	41.5							142
10/07/91	35.0	41.5	257	118	375		330		
10/09/91	35.0	41.5							143
10/14/91	35.0	41.5	98	122	220		325		155
10/23/91	35.0	41.5	31	121	121		263		

both sections, and new redds were flagged and counted during each visit to the index area (Table 11). The cumulative redd count (73) for the index area was multiplied by 2.5 adults/redd for an escapement estimate of 183 fish.

Escapement to the Newaukum Creek supplemental area was calculated as follows: *peak visible redd count in the supplemental area X (cumulative redds in the index area / peak visible redd count in the index area) X (2.5 adults/redd) = 34 X (73 / 61) X 2.5 = 102 adults.* The estimated total escapement to Newaukum Creek was *102 + 183 = 285 fish.* Usually chinook salmon can be sighted up to river mile 11.3 in Newaukum Creek. However in 1991, chinook salmon spawning activity was not observed past river mile 3.9. An interpolation table was constructed from Newaukum Creek index data to more easily relate escapement in this index area to live or dead counts in other systems where data were sparse (Table 12).

Surveys of Soos Creek recorded marked (caudal fin cut) and unmarked dead adults, plus live adults on the last day of the survey (Table 13). The escapement estimate was based upon the cumulative number dead plus the number of live adults on the last day of the survey = *165 + 39 = 204 fish.*

The total escapement estimate for the Green River system was *10,059 + 285 + 204 = 10,548 chinook salmon.* This estimate includes the Green River, Newaukum Creek, and Soos Creek natural escapement estimates.

Kitsap/Carr Inlet Streams

The Kitsap/Carr Inlet streams surveyed included Gorst, Dogfish, Clear, and Blackjack Creeks. The Gorst Creek escapement estimate was based upon a relationship with the Newaukum Creek index escapement. The live-fish-to-total-fish ratio at peak live count for Gorst Creek was 0.83 (Table 14). This ratio was compared to the same live to total ratio for the Newaukum Creek index to derive an escapement estimate: *peak live count for Gorst Creek X (escapement for Newaukum Creek index / projected live count for Newaukum Creek index at same live-to-total ratio) X (available habit / surveyed habitat) = 31 X 2.55 X 1.8 = 144 chinook salmon.*

Dogfish Creek escapement was estimated by: *peak dead fish count for Dogfish Creek X (escapement for Newaukum Creek index / peak dead fish count for Newaukum Creek index) = 31 X (183 / 54) = 106 fish* (Table 15).

Clear Creek escapement was estimated as an average of estimates from two methods. For method 1: *Clear Creek peak live fish count X (Newaukum Creek index escapement / Newaukum Creek peak live count) = 37 fish* (Table 16). For method 2: *Clear Creek peak dead fish count X (Newaukum Creek index escapement / Newaukum Creek peak dead fish count) = 82 fish.* The average of these two estimates is 60 chinook salmon.

Blackjack Creek was not surveyed in 1991. Escapement was assumed to be 1% of the Gorst Creek escapement based upon past escapement values (*0.01 X 134 = 1 fish*). Crescent and Curley Creeks (Carr Inlet) were also not surveyed in 1991. Escapement was assumed to be 33%

Table 11. Newaukum Creek chinook salmon escapement estimate – 1991.

Survey Date	Live Adults	Dead Adults	New Redds	Visible Redds	Cumulative Redds
Index (RM 0.0 to 1.0):					
9/18/91	1	0	2	2	2
9/25/91	43	1	20	21	22
10/03/91	84	17	28	47	50
10/09/91	35	54	18	61	68
10/16/91	12	35	5	56	73
Escapement = cumulative redds X (2.5 adults/redd) = 73 X 2.5 = 183 fish					
Index Ratio = index cumulative redds / index visible redds = 73 / 61 = 1.197					
Supplemental Section (RM 1.0 to 3.9)					
9/18/91	8	0		2	
9/25/91	14	1		8	
10/02/91	68	10		30	
10/09/91	17	20		34	
10/16/91	0	21		32	
Escapement = visible redds 10/9/91 X index ratio X 2.5 adults/redd = 34 X 1.197 X 2.5 = 102 fish					
Season Total Escapement = 183 + 102 = 285 fish					

Table 12. Newaukum Creek index (RM 0.0 – 1.0) projected survey data for chinook salmon – 1991.

Survey Date	Live Adults	Dead Adults	Total Adults	Daily Live	Daily Total	Live/Total
9/11/91				0	0	1.00
9/12/91				0	0	1.00
9/13/91				0	0	1.00
9/14/91				0	0	1.00
9/15/91				1	1	1.00
9/16/91				1	1	1.00
9/17/91				1	1	1.00
9/18/91	1	0	1	1	1	1.00
9/19/91				7	7	0.98
9/20/91				13	13	0.98
9/21/91				19	19	0.98
9/22/91				25	26	0.98
9/23/91				31	32	0.98
9/24/91				37	38	0.98
9/25/91	43	1	44	43	44	0.98
9/26/91				48	50	0.96
9/27/91				53	56	0.95
9/28/91				58	63	0.92
9/29/91				63	70	0.90
9/30/91				68	78	0.87
10/01/91				73	87	0.84
10/02/91				78	94	0.83
10/03/91	84	17	101	84	101	0.83
10/04/91				76	98	0.78
10/05/91				67	95	0.71

Table 13. Soos Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults
10/04/91	0.0	0.7	NC	44
10/07/91	0.0	0.7	NC	46
10/11/91	0.0	0.7	NC	28
10/16/91	0.0	0.7	39	47
Total				165

Table 14. Gorst Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
9/17/91	0.0	1.0	9	1	10
9/24/91	0.0	1.0	7	1	8
10/01/91	0.0	1.0	8	0	8
10/08/91	0.0	1.0	31	6	37
10/15/91	0.0	1.0	5	1	6
10/22/91	0.0	1.0	5	3	8
10/29/91	0.0	1.0	0	7	7

Table 15. Dogfish Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
9/16/91	0.0	0.9	0	0	0
9/23/91	0.0	0.9	7	3	10
9/30/91	0.0	0.9	12	5	17
10/07/91	0.0	0.9	35	10	45
10/14/91	0.0	0.9	11	21	32
10/21/91	0.0	0.9	13	18	31
10/28/91	0.0	0.9	11	31	42

Table 16. Clear Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
9/27/91	0.0	0.8	17	5	22
10/02/91	0.0	0.8	2	11	13
10/11/91	0.0	0.8	2	6	8
10/17/91	0.0	0.8	2	24	26
10/23/91	0.0	0.8	1	19	20
10/28/91	0.0	0.8	0	15	15

Table 17. Burley Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Daily Adults	Total Adults	Visible Redds
10/01/91	0.0	0.5	19	1	20	23
10/01/91	0.5	1.4	195	71	266	203
10/01/91	1.4	1.9	92	18	110	57
10/01/91	1.9	2.2	156	48	204	68
10/10/91	0.0	0.5	50	90	140	33
10/10/91	0.5	1.4	30	92	122	72
10/10/91	1.4	1.9	33	76	109	70
10/10/91	1.9	2.2	77	91	168	59
10/15/91	0.0	0.5	25	98	123	152
10/15/91	0.5	2.2	28	236	264	110

of the escapement to Dogfish Creek for both of these streams, based upon data from 1988 through 1990. This resulted in an estimate of 70 fish for the two streams combined (*35 + 35*).

Burley Creek escapement was estimated by: *Burley Creek peak dead fish count X (Newaukum Creek escapement / Newaukum Creek peak dead count)* which resulted in an estimate of 1,555 adults (Table 17). A second method was examined, but the results of this method were not used directly, although they were similar to the results for the peak dead fish count method. For the second method: *peak visible redd count at Burley Creek X (Newaukum Creek escapement / Newaukum Creek peak visible redd count)* yielded an estimate of 1,053 adult chinook salmon. A visible redd curve was not plotted for area-under-the curve analysis because only three days were surveyed in a span of 16 days. It is believed that a redd curve based on such inadequate data would result in a negatively biased estimate.

Total Kitsap/Carr Inlet natural escapement was estimated to be 144 + 106 + 60 + 71 + 1,555 = 1,936 chinook salmon.

Puyallup River System

Past escapements have been estimated using methods previously described by Ames and Phinney (1977) and are based upon a tagging study conducted in the 1970s (Puyallup Tribe and U.S. Fish and Wildlife Service 1977). Using these methods, the peak live fish count in the South Prairie Creek index area (RM 1.1 - 2.6) was multiplied by 37 (Table 18). For 1991, this resulted in an estimate of 1,702 chinook salmon spawners.

Nisqually River System

Because the Nisqually River is glacially fed, it is difficult to survey due to poor water visibility. Natural escapement was estimated by the following equation: *escapement = 6.81 X ((2.5 X Nisqually River peak fish count) + Mashel River peak fish count) = 6.81 X ((2.5 X 54) + 5)*. The peak redd count in the Nisqually River was recorded from RM 21.8 to 26.2. The peak fish count in the Mashel River was between RM 0.0 and 3.2. The 2.5 factor was an expansion for the observed peak escapement in the Nisqually River relative to the observed peak escapement in the Mashel River. The 6.81 factor was derived from catch data to expand the peak counts into a total escapement estimate. For 1991, this gives an estimate of 953 chinook salmon spawners.

McAllister Creek

Previous escapement estimates for McAllister Creek have been based upon two methods. For the first method:, *escapement = total of peak live and peak dead counts at McAllister Creek X (Newaukum Creek index escapement / Newaukum Creek index total peak live and peak dead counts on the same day of the run based upon the live-to-total ratio)*. The second method is: *peak live counts at McAllister Creek X (Newaukum Creek index escapement / Newaukum Creek index peak live count)*. In addition, broodstock removed from the river by the hatchery is added to the escapement estimate.

Table 18. South Prairie Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
9/04/91	0.0	3.8	0	0	0
9/13/91	0.0	1.1	4	0	4
9/13/91	1.1	2.6	8	0	8
9/13/91	2.6	3.3	0	0	0
9/13/91	3.3	7.3	6	0	6
9/24/91	0.0	1.1	14	3	17
9/24/91	1.1	2.6	46	7	53
9/24/91	2.6	3.3	6	4	10
9/24/91	3.3	5.8	39	2	41
9/24/91	5.8	10.2	4	0	4
9/24/91	10.2	12.2	2	0	2
10/04/91	0.0	12.7	80	60	140
10/14/91	0.0	2.6	29	109	138
10/23/91	1.1	2.6	2	26	28

In 1991, only one survey of McAllister Creek was conducted and that survey was near the end of the spawning season. The escapement was estimated by comparing past hatchery-to-natural escapements because hatchery strays comprise the natural spawner population. The average hatchery-to-natural escapement ratio for 1987 to 1990 was 1.91 (Table 19). Natural escapement was estimated by dividing the 1991 hatchery escapement by the average hatchery-to-natural escapement ratio, for an estimated 206 adults. The number of fish placed upstream or taken for broodstock was added to this estimate for a total estimated escapement of 407 chinook salmon.

Deschutes River

Deschutes River natural escapement was estimated as the number of Deschutes hatchery chinook salmon placed upstream of the hatchery, which was 325 in 1991. The escapements to Percival Creek and Moxlie Creek were estimated by relating peak live counts to the Newaukum Creek index escapement as described above for McAllister Creek. Total 1991 escapement for Moxlie and Percival Creeks was estimated as 139 chinook salmon.

Miscellaneous South Sound

Skookum Creek escapement was expected to be lower in 1991 than in recent years because the chinook salmon program at the Elson Creek Hatchery was discontinued in 1987, ending a source of hatchery strays to Skookum Creek. The estimate for 1991 was 356 chinook salmon, substantially below the 1989 to 1990 average estimate of 2,555 fish. However, the 1991 estimate was derived from data from a single survey on 11/01/91 (late in the season) with a large habitat expansion factor of 15, so is not considered accurate (Table 20). The escapement was estimated as: *peak dead fish count at Skookum Creek X (Newaukum Creek index escapement / Newaukum Creek index peak dead fish count) X (habitat miles available / habitat miles surveyed) = 7 X 3.39 X 15 = 356 fish.*

Escapements for Mill Creek and Kennedy Creek were estimated by: *peak live fish count for each area X (Newaukum Creek index escapement / Newaukum Creek index peak live fish count).* The estimated escapements totaled 11 fish in 1991 (Table 20).

Johns Creek, Deer Creek, Coulter Creek, Rocky Creek, and Sherwood Creek escapements were estimated by: *live, dead or total fish count for the creek in question X (Newaukum Creek index escapement / appropriate live, dead, or total fish count for the Newaukum Creek index).* This resulted in a total of 308 fish for the Johns and Deer Creek areas and 210 adults for the remaining creeks (Table 21).

Table 19. McAllister Creek hatchery and natural escapement estimates for chinook salmon, 1987 – 1991.

Year	Hatchery Escapement	Natural Escapement	Hatchery/Natural Escapement
1987	1,695	928	1.827
1988	2,250	1,977	1.138
1989	1,494	441	3.388[a]
1990	1,257	975	1.289
1991	393		

[a] This value was not an outlier using the Dixon test (Sokal and Rohlf 1981).

Average hatchery/natural escapement = 1.91 with a 95% confidence interval of 1.0 to 2.8.
1991 natural escapement = 393 / 1.9 = 206 fish with a range of 141 to 378.

Table 20. Kennedy Creek, Skookum Creek, and Mill Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
Kennedy Creek					
10/21/91	0.0	2.3	1	0	1
11/01/91	0.0	2.3	2	0	2
Skookum Creek					
11/01/91	0.2	0.7	0	7	7
Mill Creek					
10/21/91	1.0	6.5	3	0	3

Table 21. Johns Creek, Deer Creek, Sherwood Creek, Coulter Creek, and Rocky Creek chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
Johns Creek					
10/02/91	0.0	0.4	1	0	1
10/11/91	0.0	0.4	8	7	15
10/22/91	0.0	0.4	3	19	22
10/31/91	0.0	0.6	0	2	2
Deer Creek					
10/02/91	0.0	1.3	20	0	20
10/11/91	0.0	1.3	61	7	68
10/22/91	0.0	1.3	3	5	8
10/31/91	0.0	1.3	0	3	3
Sherwood Creek					
10/02/91	0.0	0.7	5	2	7
10/11/91	0.2	0.7	21	7	28
10/22/91	0.0	0.7	3	17	20
10/31/91	0.0	0.7	2	8	10
11/04/91	0.0	0.7	0	2	2
Coulter Creek					
10/25/91	0.0	1.1	25	1	26
11/04/91	0.0	1.1	10	5	15
11/12/91	0.0	1.1	0	2	2
Rocky Creek					
10/11/91	0.0	1.0	8	6	14
10/18/91	0.3	1.6	1	3	4
10/21/91	0.0	1.0	0	3	3

Hood Canal Region

Live adults, dead adults, and visible redds were counted in the Skokomish River and South Fork Skokomish River using foot and raft surveys. New redds were flagged and counted in the index area of the Skokomish River (RM 8.0 - 9.0) so that cumulative redds could be determined (Table 22). Escapement for the index area was estimated by multiplying cumulative redds by 2.5 adults/redd for an estimate of 240 chinook salmon in the index area (Table 22). For each remaining section of the river, the peak visible redd count was multiplied by the index ratio which was defined as: *(season cumulative redds in the index area / number of visible redds at peak in the index area)*. This cumulative redd estimate was multiplied by 2.5 adults/redd for an escapement estimate to the supplemental section. For river miles 2.2 - 12.7, the escapement estimate was 775 adults. The estimated escapement to river miles 0.0 - 0.2 of the South Fork Skokomish River was 183 adults.

Only part of the habitat was surveyed for river miles 2.2 - 5.5 in the South Fork Skokomish, and only one survey was performed (close to the peak). For this section, the number of visible redds was multiplied by the index ratio and by available habitat / surveyed habitat (3.3 / 0.9). The escapement estimate was 171 chinook salmon for this section. Total escapement for the Skokomish River and South Fork Skokomish River was estimated as 1,129 natural spawners.

Escapements to Hunter Creek and Vance Creek were estimated by dividing the escapement of the South Fork Skokomish River (RM 0.8 - 2.2) by 1.4 miles, and multiplying by the appropriate number of miles for each of the creeks (1.7 miles for Hunter Creek and 0.5 miles for Vance Creek) to reflect the effective total spawning habitat in miles. This assumes that Hunter and Vance Creeks have similar spawning densities as the South Fork Skokomish River. The escapement estimates for these two areas were 35 and 118 adults, respectively (Table 22).

Past estimates for Purdy Creek have either relied upon average Purdy Creek to Skokomish River escapement ratios multiplied by the current Skokomish River escapement, or have related peak dead fish counts to the escapement/peak dead fish ratio for the Skokomish index (Table 23). Several methods were tried for 1991. The peak dead fish count method produced an estimate that seemed unrealistically high (1,728 fish), considering that only 280 live fish were counted for the season, and the estimate for the remainder of the Skokomish River system was 1,247 fish. As an alternative, it was assumed that the escapement to Purdy Creek would have a relationship to the escapement to George Adams Hatchery (which is located on Purdy Creek) since natural spawners in Purdy Creek are primarily hatchery strays. From 1987 to 1990, the average natural-to-hatchery escapement ratio was 0.221 (Table 23). This was multiplied by the George Adams Hatchery escapement for 1991 to yield an estimate of 678 adults. This relationship, however, showed high yearly variation (as did the Purdy Creek / Skokomish River relationship used in the past), so another method was chosen.

The method used for 1991 plotted the number of live fish versus survey date for area-under-the-curve analysis (Figure 15). This resulted in an estimate of 437 fish. This estimate was close to the estimate from the natural-to-hatchery relationship, and it was selected as the best available estimate.

Table 22. Skokomish River chinook salmon escapement estimate – 1991.

Survey Date	Live Adults	Dead Adults	New Redds	Visible Redds	Cumulative Redds
River Mile 2.2 – 5.3:					
9/25/91	153	15		18	
Escapement = visible redds X index ratio X (2.5adults/redd) = 18 X 1.43 X 2.5 = 64 fish					
River Mile 5.3 – 6.3:					
9/20/91	45	0		30	
9/27/91	70	0		7	
10/04/91	10	7		11	
10/11/91	5	3		5	
10/18/91	1	1		3	
Escapement = peak visible redd count X index ratio X (2.5 adults/redd) = 30 X 1.43 X 2.5 = 107 fish					
River Mile 6.3 – 8.0:					
9/20/91	57	2		22	
9/27/91	87	2		63	
10/04/91	57	11		60	
10/11/91	26	27		41	
10/18/91	4	23		21	
Escapement = peak visible redd count X index ratio X (2.5 adults/redd) = 63 X 1.43 X 2.5 = 225 fish					
Index Section (River Mile 8.0 - 9.0):					
9/20/91	45	0	21	21	21
9/27/91	36	0	35	58	56
10/04/91	21	17	31	67	87
10/11/91	12	20	9	67	96
10/18/91	3	9	0	52	96
Escapement = cumulative redds X (2.5 adults/redd) = 96 X 2.5 = 240 fish					
Index ratio = cumulative redds / peak visible redds = 96/67 = 1.43					
River Mile 9.0 – 12.7:					
9/25/91	16	4		10	
10/08/91	23	9		39	
Escapement = peak visible redd count X index ratio X (2.5 adults/redd) = 39 X 1.43 X 2.5 = 139 fish					
South Fork Skokomish River (River Mile 0.0 – 0.8):					
9/20/91	14	1		7	
9/27/91	23	0		20	
10/04/91	14	7		24	
10/11/91	5	11		17	
10/18/91	3	11		9	
Escapement = peak visible redd count X index ratio X (2.5 adults/redd) = 24 X 1.43 X 2.5 = 86 fish					

- continued -

Table 22. Skokomish River chinook salmon escapement estimate – 1991 (continued).

Survey Date	Live Adults	Dead Adults	New Redds	Visible Redds	Cumulative Redds
South Fork Skokomish River (River Mile 0.8 – 2.2):					
9/20/91	11	0		14	
9/27/91	17	2		27	
10/04/91	7	6		21	
10/11/91	1	4		6	
10/18/91	3	7		9	
Escapement = peak visible redd count X index ratio X (2.5 adults/redd) = 27 X 1.43 X 2.5 = 97 fish					
South Fork Skokomish River (River Mile 2.2 – 3.1):					
9/25/91	15	0		13	
Escapement = peak visible redds X index ratio X (2.5 adults/redd) X (section miles / surveyed miles) = 13 X 1.43 X 2.5 X = 171 fish					
Hunter Creek: escapement = ((S. Fork Skokomish RM 0.8 – 2.2 escapement) / (RM of South Fork section)) X (RM of Hunter Creek used by chinook salmon) = 97 X 1.4 X 0.5 = 35 fish					
Vance Creek: escapement = ((S. Fork Skokomish RM 0.8 – 2.2 escapement) / (RM of South Fork section)) X (RM of Vance Creek used by chinook salmon) = 97 X 1.4 X 1.7 = 118 fish					
Season total escapement = 1,282 chinook salmon					

Table 23. Purdy Creek chinook salmon escapement estimates, 1987 - 1991.

Year	Skokomish Escapement	Purdy Creek Natural Escapement	George Adams Hatchery Escapement	Purdy Escapement / Skokomish Escapement	Purdy Escapement / Hatchery Escapement
1987	964	1,002	3,191	1.04	0.31
1988	1,317	1,215	4,439	0.92	0.27
1989	788	411	2,523	0.52	0.16
1990	351	291	2,186	0.83	0.13
1991	1,147		3,068		
Average				0.83	0.22

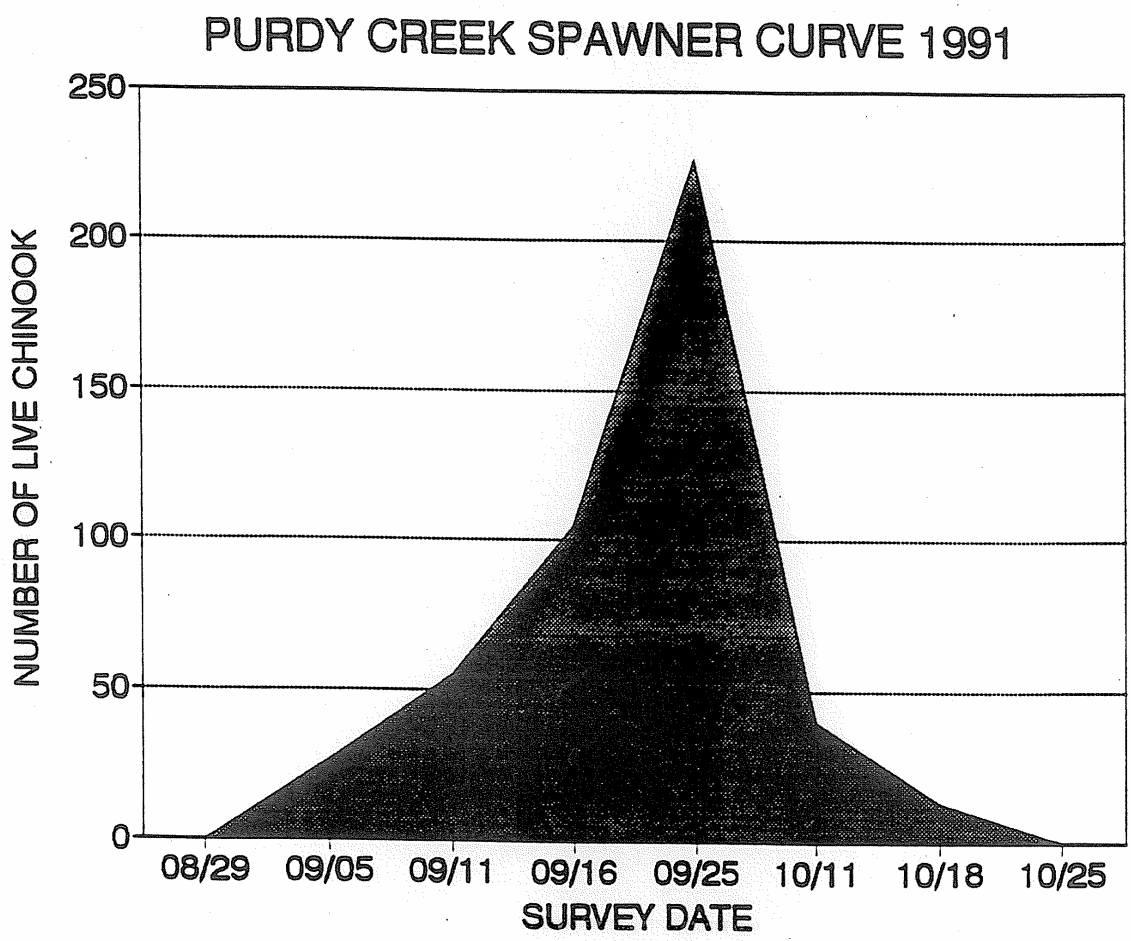

Figure 15. Live chinook salmon counts in Purdy Creek by survey date plotted for area-under-the-curve analysis.

Escapements to the Hamma-Hamma River and miscellaneous Area 12D streams (Dewatto, Union, and Tahuya) were estimated by: *peak live fish count in each stream X (escapement for the Skokomish River index section / peak live fish count for the Skokomish River index section) X (available habitat / surveyed habitat)*. The estimated escapements were 30 chinook salmon for the Hamma-Hamma River and 53 chinook salmon for the miscellaneous 12D streams (Table 24).

The Duckabush River and Dosewallips River were probably surveyed after the live fish peak and only small sections were surveyed. Because of the large expansion factors that would be necessary for each of these rivers using the above methods, escapement was estimated as: *(greatest number of live and dead fish on a given date) X 2*. The estimate for the Duckabush River was 14 adults and the estimate for the Dosewallips River was 42 fish (Table 25). The factor of 2 was chosen based upon differences in past escapement estimates at peak versus the survey dates in 1991.

Table 24. Hamma-Hamma River and Union River chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
Hamma-Hamma River					
10/03/91	0.3	1.8	2	0	2
10/10/91	0.4	1.8	5	1	6
10/17/91	0.3	1.8	1	9	10
10/24/91	0.3	1.8	0	3	3
11/01/91	0.4	1.8	0	4	4
Union River					
9/18/91	0.3	2.1	6	1	7
9/27/91	0.3	2.1	4	14	18
10/07/91	0.3	2.1	2	9	11
10/16/91	0.3	2.1	0	3	3
12/02/91	0.3	2.1	0	1	1

Table 25. Duckabush River and Dosewallips River chinook salmon survey data – 1991.

Survey Date	Lower River Mile	Upper River Mile	Live Adults	Dead Adults	Total Adults
Duckabush River					
10/03/91	0.0	2.3	7	0	7
10/10/91	0.0	2.3	1	0	1
10/24/91	0.0	2.3	0	1	1
11/01/91	0.0	2.3	0	1	1
Dosewallips River					
9/30/91	0.1	6.7	4	1	5
10/08/91	0.0	2.3	9	5	14
10/08/91	2.3	6.7	4	3	7
10/22/91	0.0	6.7	0	2	2

DISCUSSION

There are many problems associated with the above escapement estimation methods but the choice of method often results from a compromise between maintaining consistency and minimizing the errors and cost of the estimate. Some of the sources of counting errors include water visibility effects, surveyor errors, carcass flushing, inability to survey at peak spawning, false redds, and the percentage of redds not identified during aerial surveys. These errors can be decreased by adjusting for visibility conditions, training and maintaining a consistent survey crew, using carcass counts sparingly, surveying more intensely around peak spawning time based upon past run timing data, and correcting for unseen redds from aerial surveys by ground surveying a portion of the aerial surveyed area on the same day.

Other sources of error are present in data handling and analysis. These result from: area expansions that assume similar habitat utilization; changes in index conditions with time; expansions of survey life or redd life estimates to other streams; the assumption of constant sex ratio from stream to stream; and using an escapement estimate from Newaukum Creek as the basis for the escapement estimate to streams in other drainages. Some of these sources of error have been addressed during the estimation process. The assumption of similar habitat utilization is verified by a supplemental survey near the expected peak coincident with surveys of the appropriate index area and, in many systems, supplemental sections are surveyed weekly. Index conditions are examined during the survey process to monitor changes in spawning habitat. Also, the use of an escapement estimate from Newaukum Creek to derive an estimate for another creek is used for small streams that do not contribute significantly to overall escapement. The more serious sources of error appear to be the assumptions of consistent residence time, redd life, and sex ratio. These may vary not only between drainages, but also from year to year.

Although the live fish area-under-the-curve method is superior to using only peak live counts, the accuracy of the estimate depends not only upon the survey numbers, but also upon the value of survey life, or chinook residence time on the redd. Other studies have indicated that residence time varies significantly from stream to stream, or year to year, so that values from one stream or year may not apply to another (Perrin and Irvine 1990).

The assumption of 10-day residence time used for the above estimates is supported by data from a study of spawning chinook salmon on the Morice River (a tributary of the Skeena River), but is not supported by data gathered from chinook salmon in the Nechako River (a tributary of the Fraser River). On the Morice River, average residence time ranges from 13 days early in the season to 8 days late in the season (Neilson and Geen 1981). On the Nechako River, females averaged 15 days residence time early in the season to 12 days late in the season (Neilson and Banford 1983).

An average 10-day residence time is used for chum salmon escapement estimates in Puget Sound (Ames 1984). For chinook salmon in Puget Sound river systems, the average residence time is unknown, as is variation that might exist between different river systems. Since the escapement estimate is acutely influenced by residence time, it would be very useful to conduct future studies investigating chinook salmon residence time in a few diverse Puget Sound river systems.

Several of the Puget Sound chinook salmon escapement estimates are calculated using area-under-the-curve estimation for visible redds. This method depends not only upon an accurate count of visible redds over the spawning season, but also upon an accurate redd life value. Chinook salmon redd life averaged 21 days in a study conducted on the Skagit River (Orrell 1976). However, additional studies are needed to assess redd life in other river systems and to assess annual variation of redd life. Another factor used in the area-under-the-curve analysis is the assumption of 2.5 fish/redd. This was based upon a study in the Skagit River (Orrell 1976), but should be examined in other river drainages.

The most accurate method of estimating escapement is by cumulative redd counts, where each new redd is recorded and flagged on a weekly basis. Since this procedure is labor intensive, it is usually reserved for index areas in a variety of streams. The escapement results from these index areas are often expanded to the remainder of the river through comparisons with the number of visible redds counted in the supplemental river sections. If the index escapement is expanded to the remainder of the river sections without surveys in the supplemental sections, the choice of the index area is critical. In such cases, the index area should be representative of the entire stream, i.e., the population in the index area should be proportional to the population of fish in the entire system and a consistent proportion of the run should spawn in the index area each year (Mundie 1984). Our reliance on the stability within the index section is reduced because most of the available habitat is surveyed and visible redds are enumerated in the supplemental sections as well as in the index area. Therefore, changes in habitat conditions should be reflected in the visible redd count and thereby accounted for.

Specific escapement estimation problems exist in the North Fork Nooksack River and Puyallup River due to poor water visibility conditions. Carcass counts have been used in the North Fork Nooksack River as an index of relative abundance. In the Puyallup River system, South Prairie Creek has been consistently surveyed by WDFW with the results used to derive the escapement for the remainder of the basin. Future surveys are planned by the Puyallup Tribe to re-examine escapement in the Puyallup River basin.

Despite these problems, there is little question that the comprehensive escapement surveys performed by WDFW and the Tribes in the Puget Sound region have produced a strong database necessary and useful for salmon management. It is hoped that this documentation of escapement estimation methods will provide guidance to allow the development of techniques to maintain or improve the accuracy and precision of Puget Sound escapement estimates.

ACKNOWLEDGEMENTS

We greatly appreciate the editorial comments provided by Bill Tweit (WDFW), Chuck Baranski (WDFW), and Dr. Sandy Moore (WDFW). We are also indebted to Catie Mains (WDFW) and Jan Green (DOT) for the creation of the Puget Sound chinook salmon stream map. Jim Irvine, Canadian Department of Fisheries and Oceans, kindly provided a timely review of this report.

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